ENVIRONMENTAL REQUIREMENTS FOR OPTIMAL NAVAL OPERATIONAL EFFICIENCY

by

R.L. UYS

Thesis presented in fulfilment of the requirements for the degree of Master of Science in Oceanography at the University of Cape Town

Prof G.B. Brundrit
Supervisor

CAPE TOWN

January 2004

To my father, Dries Uys, and late father-in-law, Dries Struwig.

ABSTRACT

In this thesis the applicability of ocean environment modelling as a part of optimal naval operational efficiency, and thus military oceanography, is evaluated. To be able to do this, the principles of knowledge-based warfare and the ability to make rapid environmental assessments, are introduced. These then form part of optimal efficiency. Modelling of the environment implies knowledge-based warfare and accommodates the ability to make a rapid environmental assessment.

After an overview of past and current ocean modelling (specifically wave modelling), the third generation SWAN (Simulating WAves Nearshore) model is selected to model a small component of the military oceanographic spectrum viz. waves. The selected area, includes an area where the US Navy conducted an amphibious landing exercise (Operation Laurel) during October 2001.

Three case studies are considered for modelling. These included an extreme wave condition, a mode wave condition and the conditions during Operation Laurel. Data were obtained from the wave rider buoy at Slangkop near Cape Town and analysed for a specific period during 2001. In all three cases the wave dissipation and maximum energy transfer areas were determined from the model. From these, certain deductions could be made regarding the influence the environment under these three different conditions could have on naval operations in the littorals.

It is concluded that ocean modelling should form an integral part of naval operational efficiency and its contribution as force multiplier should be taken into consideration.

ACKNOWLEDGEMENTS

I would like to acknowledge a number of parties who contributed to the successful completion of this thesis:

I would like to thank Marius Rossouw, André van der Westhuyzen and Steven Luger from the CSIR for all their contributions and assistance.

I would like to thank Mr Hennie Smit, Capt Hennie Janse van Rensburg and Lt Col André Jacobs from Military Geography at the Military Academy, for all their assistance and support.

For their inputs on military trends, I would like to thank Mr Carl Wainman from IMT and Cdr Johann Uys Officer Commanding of SAS GALESHEWE. Also to Capt(SAN) L. Reeder and Capt(SAN) A. Kamfer (past and present Hydrographer of the SA Navy) for permission to reproduce naval charts in the thesis, as well as their staff for their assistance.

For the supplying of high and low altitude photos, I would like to thank the following members of the SA Air Force: Col de Pinho, Lt Col Engelbrecht, Lt Col Swart and Capt Gomez. Also for his assistance with the physical measurements of the beach slope, I would like to thank Lt Col Eckert.

I would like to express my sincere gratitude towards Me Ariane Neethling for her assistance with the statistical analysis of the data.

I would like to thank Prof Gerrie Thiart, my colleague at Nautical Science, for all his patience, assistance and for taking over some of my lecturing responsibilities.

I would like to thank Prof Johan Lutjeharms whom have set me on my way before he fell ill, my study leader Prof Geoff Brundrit for his thorough and professional supervision and my co-study leader Dr Hardus Diedericks from the University of Stellenbosch, for guiding me through the modelling with SWAN.

Lastly, to my wife Helenette and daughter Anneen, thank you for being so patient.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF DIAGRAMS

LIST OF PHOTOS

LIST OF APPENDICES

CHAPTER 1

1.1 INTRODUCTION

The tactical advantage will probably not depend on who has the most expensive, sophisticated platforms – but rather on who can most fully exploit the natural advantages gained by a thorough understanding of the physical environment.

– Rear Adm W.G. "Jerry" Ellis, USN, Oceanographer of the Navy 1999
(as quoted from Oceanography and Mine Warfare, 2000)

1.2 THE ROLE OF THE SA NAVY

The first and foremost obligation of the SA Navy is the protection and sustainment of the country's maritime zones. Included in this obligation is thus safety at sea, the Navy's role in hydrographical surveys (safe navigation) and Search and Rescue operations. The country's Search and Rescue area of responsibility is vested by convention of the International Civil Aviation Organisation (ICAO) and the International Maritime Organisation (IMO) and it stretches from the Namibia – Angola border to the RSA Mozambique border (totalling to approximately 17,2 million km^2) (SANDF Intranet, 2003).

The SA Navy has further commitments towards ensuring the following: safe maritime trade (directly or indirectly); serving the economies of the region; as well as maritime regional co-operation and assistance operations (SANDF Intranet, 2003).

In terms of maritime defence, the SA Navy summarises its role as follows (SANDF Intranet, 2003):

"The role of the SA Navy is to prepare for and, when so ordered, to conduct:

- Appropriate naval operations in defence of the RSA, its citizens and interests; and
- Operations other than war in support of other relevant and approved national goals."

The SA Navy's main tasks include the maintenance, preservation and the provision of naval services in support of other state departments and authorities, where such assistance include the following:

- Search and rescue;
- Protection of maritime resources;
- Sea transport; and
- Diplomatic support. (SANDF Intranet, 2003)

"...It is this sea route that is the Navy's ward. It is the Navy's duty to police it. It is the Navy's duty to watch it. It is the Navy's duty to care for its users – the mercantile fleets of the world. For this they work...."
– Cdre J. C. Goosen SM (Goosen, 1973)

1.3 BACKGROUND

The South African Navy (SAN) has a local responsibility of applying its forces along a coastline of approximately 2800 km around a geo-strategically positioned country. Given the current limited availability of ships, this remains a very large area to cover. The alternative to not having a large enough fleet and still striving to gain advantage through superior naval combat power, is to have knowledge superiority particularly of the local natural environment. Given the existing limited capacity of the SAN fleet and the planned expansions, it must be borne in mind that the number of available vessels still has to be sub-divided into different specializing divisions, such as

- Combat support (SAS OUTENIQUA, SAS DRAKENSBERG, SAS PROTEA)
- Surface warfare (Strike craft)
- Sub-surface warfare (Submarines)
- Mine countermeasure (MCM) vessels (Mine sweepers and Mine hunters).

These divisions offer a vast array of capabilities, but the number of vessels in each division is too relatively small to be constantly deployed around the SA coast. It would thus be sensible for smaller navies, such as the SA Navy, to rather gain the advantage in its local natural environment through superiority of knowledge.

An understanding of the physical environment (the battlefield) is of utmost importance. The near-shore region (littorals) is a complex area, which is constantly changing. All relevant information about it might not be available when planning operations in a specific area. Nevertheless, modelling of the battlefield has been done for many years when historic combatants planned their tactics, and in today's modern era of high technology and processing power, there are even certain models available to generate close approximations of what can be expected from the environment in the battlefield area. Such computer models, acting as a force multiplier, are currently used worldwide for military and non-military purposes.

During symposia held by the US National Research Council, some common shallow water oceanographic needs were identified i.e. the need to understand near-shore dynamics for mine warfare and mine counter warfare, anti-submarine warfare, amphibious warfare and special warfare (Ocean Studies Board, Commission on Geosciences, Environment, and Resources, National Research Council, 2000). A study of all these important battlefield operations would result in many volumes of manuals and written doctrine. Thus, the discussion of a common factor, the battlefield area, would be an important starting point for such a study.

For the SA Navy, the modelling of an informed battlefield-area selection under a range of known environmental conditions common to the area would be an excellent starting point. For the purpose of this study such an area was chosen in the form of a long sandy beach environment, typical from most of the coastline of South Africa. This study highlighted certain constraints/risks for specific military operations.

1.4 AIM OF THE STUDY

The overall purpose of this study is to investigate wave behaviour in the area between Laaiplek and Dwarskersbos on the West Coast of South Africa, from a military oceanographic perspective, using the numerical wave model SWAN (Simulating WAves Nearshore). The research area is also the area where the US Navy conducted their Operation Laurel, a humanitarian exercise involving amphibious landings (Navy News, 2001). Prior to these landings, special surveys were done to characterise the "battlefield" and to determine the feasibility of such an exercise.

The usage of the SWAN model and more specifically the results, are then compared to optimal naval operational efficiency to determine its place in military oceanography.

1.5 PROBLEM STATEMENT

The main question that this study aims to answer is:
To what extent does ocean environment modelling (specifically the SWAN model) in the littorals form part of optimal naval operational efficiency (and thus military oceanography)?

1.6 THESIS OVERVIEW

The thesis starts with a look at the SA Navy and its role, followed by a general overview on the importance of local environment knowledge that could be optimised by modelling the battlefield. The primary part of the thesis centres around ocean modelling in the littorals. The specific model chosen for this study is the SWAN (Simulating WAves Nearshore) model, which is currently a state of the art third generation model. Chapter three deals primarily with the history of ocean models and current models used and it concludes with detail on the SWAN model.

In the second chapter the military component of the study is discussed, which will emphasize the importance of military oceanography and its role as force multiplier especially for smaller navies. The principle of operational efficiency is also discussed in this chapter.

The SWAN model is applied to a specific coastline at the West Coast of South Africa namely St Helena Bay. Chapter 4 is dedicated to introducing the research site and its characteristics. Included are personal observations as well as findings by the SA Navy when surveyed for Operation Laurel (later explained).

Two main sources of data were available (both from the CSIR at Stellenbosch) on wave conditions around the South African coast, as indicated in chapter 5. One was VOS (Voluntary Observation Ship) data and the other was from the wave rider buoy at Slangkop (near Cape Town). A statistical test was done to indicate why only the wave rider data was used. The rest of chapter five comprises data analyses of wave climates for a specific period, showing polar directional distributions and histograms of wave height, period and directional distribution. The second part of chapter 5 then indicates how the model is set up. This includes a short explanation of the flow of data from input requirements to output visualisation, coordinate system used, numerical grids used and their orientations. The specific parameters activated and de-activated in SWAN are also shown.

The results of the model are reflected in chapter 6. Three events (cases) were selected to identify input data. The case studies done were those for extreme wave conditions, the mode case of the wave climate for the period selected, and the wave climate three days prior to Operation Laurel on 18 October 2001 (explained in more detail in chapter 4). The output shown from the model, per case study, are large scale and small-scale charts showing changes in wave properties, as well as energy transfer.

In the discussion in chapter 7 the importance of the changes in wave condition, specifically the energy transfer regions and its importance in military oceanography are indicated. From the results the importance of knowledge of the littoral environment on operations like mine warfare and amphibious landings, are clearly visible.

Chapter 8 summarises the study and certain recommendations are made for possible future research.

CHAPTER 2

NAVAL OPTIMAL OPERATIONAL EFFICIENCY

2.1 Introduction

For a navy to be optimally efficient it does not only mean to have superior weaponry, communications and platforms, but also accurate, rapid, long-range (oceanographic) products, which could be restrained by personnel, communications capabilities and computational resources (Burnett et al., 2002). In the modern day navy the emphasis has clearly been shifted to network centric warfare in the modern technological era. Network centric implies that all information sources (input) are brought together and evaluated (processing) to produce a feasible solution (output) in determining success. The whole process thus boils down to having a wide as possible spectrum of data and the necessary knowledge to interpret the data. Knowledge based warfare leads to optimal applying of forces (Chu, 1999). These include both offensive and defensive situations, thus attacking from the sea as well as defending from the land.

2.2 Knowledge Based Warfare

Reconnaissance and "environmental intelligence" reports have been proven vital in many a battle. In December 1944 the Third Fleet suffered severe losses (778 men, ±100 aircraft and three destroyers) due to lack of in-time information about a typhoon, whilst several of the skippers knew about the approaching storm long before the aerology staff issued any warning (Calhoun, 1981).

When planning warfare in the littorals, one has to consider all the different platforms that could be applied in this zone. These could include (but not be limited to) mine warfare and mine counter measures, amphibious landings, reconnaissance vessels and support craft. In this study, littoral warfare will be narrowed down to only considering the land-sea interaction zone. Thus the operations considered will be limited to mine warfare (MW), mine counter measures (MCM), reconnaissance and because mines can be used from blue-water, green-water right through to the brown-water arena, it necessarily includes land approaches from the sea onto the beaches, i.e. amphibious landings (AW).

Mines are relatively cheap, could migrate and could have stealth capabilities. In table 2.1 indicates the various types of mines and depth divisions are shown.

Surf Zone and Craft Landing Zone (CLZ)	**Very Shallow Water**	**Shallow Water**	**Deep Water**
0' – 10' (0 m – 3 m) Anti-Invasion, Buried/Partially Buried	10' – 40' (3 m – 10 m) Buried/Partially Buried, Bottom	40' – 200' (10 m – 65 m) Bottom, Moored	Over 200' (over 65 m) Floating, Rising

Table 2.1: Depth divisions and associated types of mines. (Ocean Studies Board, Commission on Geosciences, Environment, and Resources, National Research Council, 2000)

All the mentioned operations will require knowledge of the warfare arena, not just to know where to strike and how, but also to know what type of environment to expect. The physical environment includes a wide spectrum of factors to consider, but all the components will not necessarily be available. The ocean and/or ocean bottom can easily serve as a no-cost platform for the delivery of weaponry like the Checkmate self-burying mine. Tests have shown that the delivery canister can bury itself completely in water-covered sediment in approximately 30 seconds. To date of the article, there is no equipment available, including parametric sonar and/or blue/green laser, which is able to counter Checkmate (Hicky, 1998). Thorough knowledge of the sea bottom, including sub-bottom profiles, could, however, largely assist to counter such a sophisticated threat. Yunker states in his paper on access denial due to mines, that "an operational concept – not just a piece of equipment – is needed to meet the mine threat in and around the surf zone" (Yunker, 2001).

The need for knowledge supremacy of the environment is thus clear. It is, however, not only required to know what is happening, but also to know what you don't know. What a country is ignorant about is exactly what a foreign country/competitor will focus on. As Commander J. Patch so clearly states: "A fundamental principle of international relations is that states enjoy no permanent friends, only permanent interests" (Patch, 2003). He further states that it is naive to believe that only anti-US states (or anti-RSA states) monitor US (or RSA) maritime capabilities and limitations.

These capabilities would include environmental data, data acquisition and interpretation – military oceanographic capabilities (Patch, 2003).

2.3 Environment

The warfare arena is influenced by the integrated natural harmony of the land, sea and atmosphere. Man, therefore, cannot disturb this harmony, temporarily, it will have long-term effects. Thus, man has to learn how these three components work on their own as well as how they interact. For the purpose of this study only the (littoral) ocean component of the environment will be considered and not the terrestrial or atmospheric components.

2.4 The Ocean Environment (Military Oceanography)

Some navies in the world consider oceanography as an integral part of its support system to feed the force commander with hind cast, now cast and forecast information. These navies could roughly be narrowed down to the blue-water navies of the world. These would include larger countries like the United States of America, Britain etc. Such navies will most probably be staffed with an Oceanographer of the Navy, as is the case in the USA, whilst smaller brown water navies would only focus on the hydrography sub-component and will incorporate the oceanographic requirements of the fleet under this heading, as is the case in South Africa.

The SA Navy also addresses the general oceanographic need under the *HYDROGRAPHY* paragraph in the *South African Navy Review 2001*. Apart from navigational safety, which the hydrographer as a member of the IHO provides, he is also tasked to provide "as much information as possible about the operational environment" in which the SA Navy's ships and submarines operate (SA Navy Review, 2001). The hydrographer plays a pivotal role in supplying all tactical environmental information.

2.5 Naval Responsibilities towards Oceanography

Military oceanography requirements should lie primarily within the navy. Navies in general should, however, be supported by civilian or semi-military institutions, as is the case with the SAN (supported by IMT), which will allow for a broader spectrum of knowledge sharing. In the case of the USN, the Oceanographer of the Navy is responsible for the fleet's oceanographic requirements and research is done at the ONR (Office of Naval Research) and NRL (Naval Research Laboratory) (Burnett et al., 2002).

Why is operational oceanography so important? Why should smaller navies invest in the development of ocean prediction and forecasting? The simple but important answer is that for small navies the principle of force multiplication applies. The second, but not less important reason, is to protect naval personnel and ships in the harsh environment they operate in. In the past the lack of knowledge advantage has proven to increase the potential number of losses in combat. Knowledge of the oceans and being able to forecast it provide any navy with a tactical advantage and ensure the safety of its men. In the littorals, the forecasting just becomes more involved in making a 4-dimensional (x, y, z, time) prediction. The navy carries these responsibilities not in wartime only, but also in times of peace. During peacetime, it strengthens the ability to respond rapidly and effectively in any crisis, and promotes flexibility, mobility and interoperability with other units. Furthermore it can describe the ocean environment's effect on people and marine life, but more importantly its effect on weapons and sensors (Burnett et al., 2002).

2.6 Military Oceanography Composition

Military oceanography is significant in al the sub-divisions of the general oceanography field, i.e.:

- Geological oceanography
- Physical oceanography
- Biological oceanography
- Chemical oceanography

These sub-divisions all form part of the total tactical picture, to a more or lesser extend. Although the atmosphere also has an effect on all these sub-divisions, the ocean is approximately 30 times more complex than the atmosphere (Wainman, 2003), and thus requires much more research.

The essence of military oceanography lies in "the acquisition, compilation and release of tactical relevant information in a tactical relevant time frame" (Robinson & Sellschopp, 1999). Although tactical information could be difficult to obtain if one is not geared to do it, the tactical relevant time frame need not necessarily be constant. It is critical for any navy to be able to make a rapid appreciation of the environment when detailed information is not at hand. This, however, is not limited to making short term weather forecast, but also to be able to appreciate the whole integrated environmental picture, from the past, present, and in the future. The knowledge must be applied in the operational field, making operational oceanography the force multiplier. Robinson and Sellschopp call it "adding *weather* to *climate*" (Robinson & Sellschopp, 1999). Could it not be in a navy's best interest and to its advantage to be able to make observations, add it into a model, and being able to make rapid environmental assessments from the model in future?

2.7 Optimal Operational Efficiency (Military Oceanography)

Ideally, all role players achieve operational efficiency in a network centric environment with the simultaneous sharing of data. This can be achieved by REA (Rapid Environmental Assessment), together with integrated system and platform capabilities, the processing of data and the sharing of knowledge. "The purpose of most tactical data systems, including the new C4I systems, is to provide the local commander with the most complete possible data about his surrounding area" (Friedman, 2000). The larger the area of interest, the more information needs to be processed; the more complex the area is (littoral warfare) the more diverse information needs to be processed. To conduct an operation, the commanders of the different units must be able to see the same tactical picture of the arena at the same time.

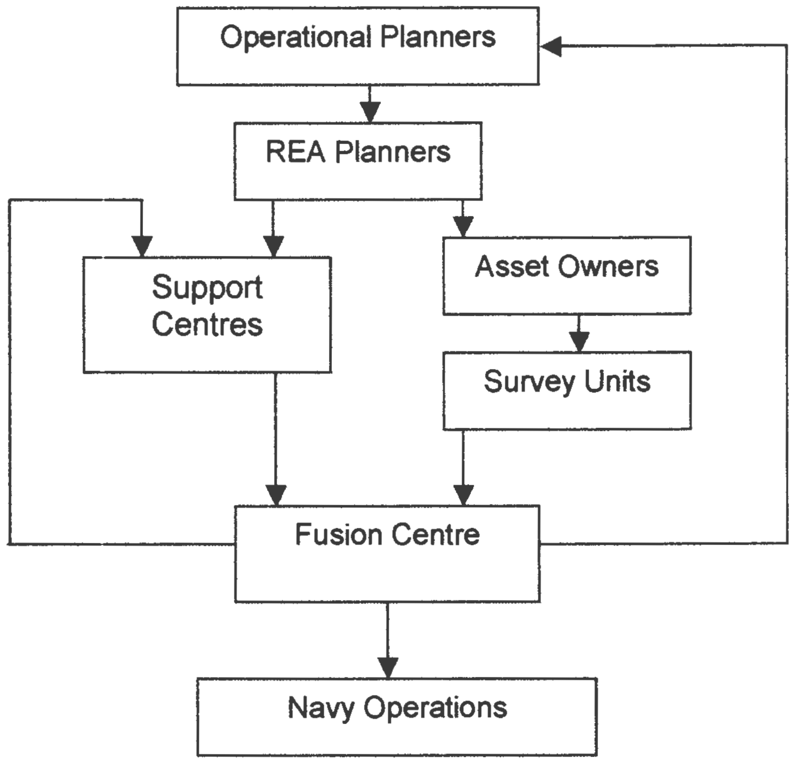

Figure 2.1: Rapid Environmental Assessment diagram. (Sellschopp, 1999)

Rapid environmental assessment entails regarding data that can be obtained in a short time to make an informed decision when information from the normal channels is not available (Sellschopp, 1999). It is more than just looking at the clouds and deciding that it will be raining soon. Figure 2.1 is a schematic representation of the components of a REA system as indicated by Dr Jürgen Sellschopp, previously from the NATO SACLANT Undersea Research Centre.

The environmental product required for naval operations might come from various data sources as in the case of an amphibious landing where surf at a beach is required: ocean swell from satellite remote sensing; a bathymetric chart from the hydrographer for wave refraction; beach slope from depth measurements by airborne laser; wind from an atmospheric forecast, etc. (Sellschopp, 1999)

The various data sources of the abovementioned environmental product form part of a wider group called METOC, which comprises various meteorological and oceanographical parameters. Prof. Chu of the Naval Postgraduate School (Monterey (USA)), indicates in a graphical representation (figure 2.2), the rate of change between the unknown METOC (Meteorology and Oceanography) data and the MOE (Measure of Effectiveness):

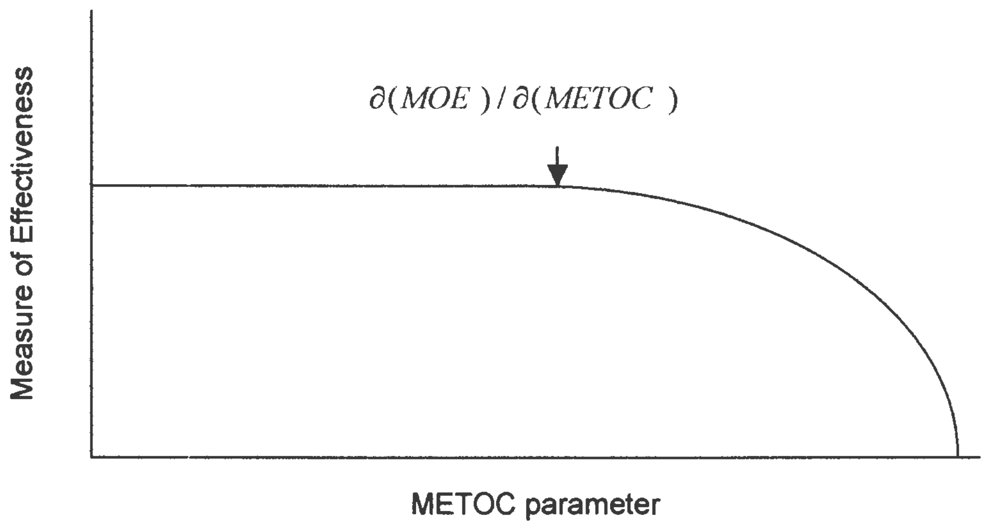

Figure 2.2: Measure of Effectiveness compared to the METOC parameter. (Chu, online 2001)

The point at which the change in METOC resolution/parameter stops influencing the Effectiveness, will be determined by accuracy, available resources etc. and the satisfactory point on the graph for the go-ahead of operations, must be decided, in this case, by a well informed and/or environmentally educated, combatant.

2.8 Operational Oceanography

The ability to model the ocean environment is of just as much importance to the military as it is to the private sector. The private sector builds the economy and the military must protect it. The smaller the naval capabilities to coastal waters ratio, the more important forecasting of the environment (ocean) becomes. To support operational oceanography, the ability to acquire as much of the most relevant data should be exploited to fuse data with knowledge. The following is an extract from the US Research Council on *Environmental Parameters and their Importance to Mine Warfare,* indicating the general importance of ocean modelling (Ocean Studies Board, Commission on Geosciences, Environment, and Resources, National Research Council, 2000):

> "the need for enhanced predictive (wave) modelling capabilities for a wide range of oceanic processes that will greatly enhance the war fighter's ability to turn vast amounts of oceanographic information into knowledge used to control battlefield operations"

The accurate modelling of coastal zone processes is difficult, but this should not be a reason not to encourage it, and apply the results toward quantitative descriptions of shallow water oceanography. The usefulness of such outputs could greatly be enhanced by real-time 3D graphical representation of results. This "Virtual Oceanography" will enable war fighters to visualise and manipulate data in a more intuitive manner (Ocean Studies Board, Commission on Geosciences, Environment, and Resources, National Research Council, 2000).

To take advantage of the continuing advances in computational abilities for Operational Oceanography, we need to revisit the requirements in the planning of monitoring systems (Prandle, 2000). The spatial and temporal coverage of models as observational/monitoring system is indicated in figure 2.3.

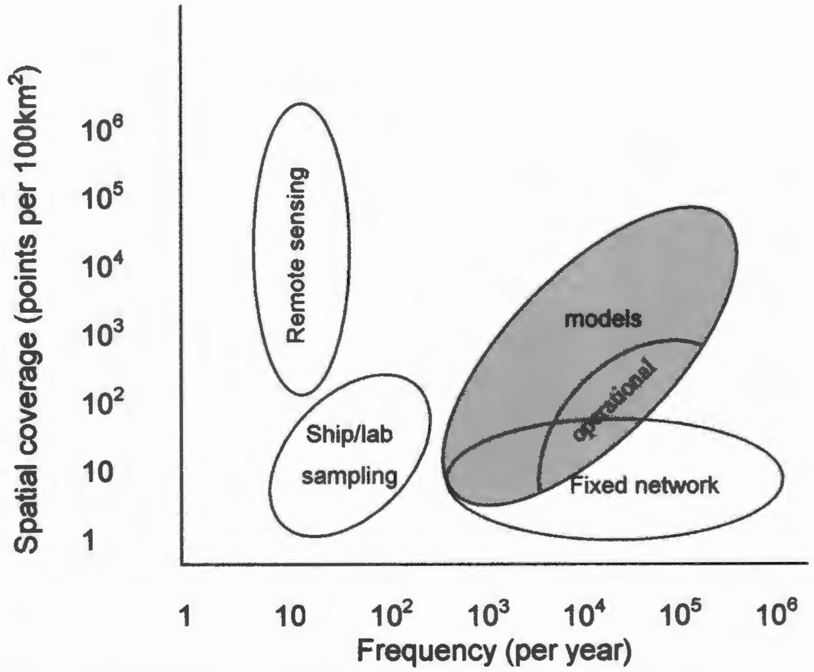

Figure 2.3: Spatial and temporal coverage of various observational/monitoring systems. (Prandle, 2000: Personal conversation between Prandle and Van Ruiten)

Operational oceanography clearly forms a part of the broader modelling system, of which the importance of frequent large resolution spectrum modelling is indicated.

In a military context, operational oceanography forms part of the operational plan. Operational oceanography in a defensive operation in a known battle space will imply knowledge superiority, as it is assumed that such a country has all relevant in-time data available and can predict accurate answers in advance. This principle links to the concept of knowledge-based warfare (KBW).

2.9 Operational Oceanography Needs (SAN)

To be able to fight and win at sea implies having some advantages over the enemy, which are greatly enhanced by understanding the sea (and weather) at the time, historically and in the future, both in time and space (Wainman, 2003). Every country will have its own unique military oceanographic needs, depending on its global location and size, borders, geographic design, coastline length, etc. Such is the case in South Africa, having a unique meeting point of three southern hemisphere oceans.

The following table (2.2) represents a short indication of a whole spectrum of identified needs, for the SAN (in no specific order).

Need	Motivation
Underwater Sound Velocity	Submarine stealth, target ranging, MCM
Internal Waves	Submarine stealth, buoyancy, underwater stability
Background Noise	Vessel stealth
Currents	Vessel progress (Agulhas and Benguella currents)
Wind	Vessel sea keeping, search and rescue, wave and current generation, visibility and sensor interference
Cloud Cover	Visibility, stealth, joint operations (airforce), infra red sensors and radar interference.
Ocean Fronts	Plankton and fish occurrence (vessel stealth)
Fish and Plankton	Intelligence guide for vessel traffic, submarine stealth
Beach Profile and Tides	Ad hoc beach landings
Riverine Warfare	Vessel buoyancy, diving
Bioluminescence	Visibility of vessels and divers
Seafloor Nature	MCM
Seafloor Characteristics	Submarine bottoming, MCM

Table 2.2: SAN Operational Oceanography Needs. (Wainman, 2003)

Not mentioned in the above table is the SA Navy's responsibility towards Antarctic support. One could further add to the above list knowledge unique to the Southern Ocean. This could include major ocean currents and accompanying currents, the scope of the ice fields, ice field thickness and occurrence of icebergs. (Lutjeharms et al., 1998)

Ocean modelling assists in making rapid environmental assessments and broadens the knowledge of the environment. Many countries are involved in ocean modelling under various categories. The next chapter will provide an overview of such modelling, endeavours in the past and the present.

CHAPTER 3

Military Oceanography and Littoral Ocean Modelling

3.1 Introduction

Oceanography as a distinctive field of military study that emerged in 1855 when Lieutenant Matthew F. Maury published *The Physical Geography of the Sea* (Collins, 1998). The current situation is one of sudden awakening of the real problem that exists for navies in the littoral ocean area. In his book *"Fleet Tactics and Coastal Combat"*, Retired US Navy Captain W.P. Hughes admits "littoral operations are now so prominent and affect so much tactical planning ... I am not sure I give this subject (*Tactical Environment*) the attention it deserves".(Hughes, 2000) With the end of the Cold War and the migration of a mindset from blue-water navy to brown-water navy, one has to accept that the physical geographical ocean environment emerges as a difficult variable to solve (sometimes to estimate only!). "Every body of water requires a different set of tactics" (Admiral T. Hayward as in Hughes, 2000).

The body of water, or more specifically the arena, which will be considered in this thesis, will be the littoral zone. The littoral zone, also known as the brown water arena, with as many definitions of dimension as there are military oceanographers, is generally approximated as the area contained from 200 NM seaward to 60 NM landward. For the purpose of this study, the near coastal zone from approximately 200m water depths to the shoreline will be considered only.

3.2 Current Trends in Military Oceanography (and Littoral Warfare)

A great many lessons were learnt in previous wars on land regarding applicable tactics for certain operating theatres. A good example would be to compare the Vietnam War environment with the war environment encountered in Iraq (in the war against terrorism). Similarly, one cannot employ the same tactics in the different war theatres at sea. The littoral zone becomes a very complex area to analyse. When planning an offensive, information on the environmental conditions and especially the coastline conditions, are not always available. Without proper reconnaissance, the only information available would be that which is found on navigational charts and whatever knowledge can be derived from satellite information.

It is probably these deltas (unknowns), which brought the USN to form a special detachment unit for shallow water and very shallow water (10 to 40 feet), operations. The Very Shallow Water Mine Countermeasures detachment, formed in 1996, has to apply the talents from three different war-fighting communities (Brackenbury, online 2003). This detachment's role is to detect and remove mines and obstacles in shallow water to facilitate in amphibious landings. Brackenbury quotes one of the team's senior explosives ordinance disposal (EOD) technicians, Boatswain's Mate 1st Class B.S. Roberts, "We are the only people in the world doing this" and "Everyday we're writing our own doctrines". (Brackenbury, online 2003)

The National Ocean Analysis and Prediction laboratory was recently established in the oceanography department at the Naval Postgraduate School in Monterey in the US (Chu, online 2003). The following three concepts indicate their interest:

- What is the measure of effectiveness of environmental knowledge
- What are environmental effects on littoral warfare; and
- To educate naval officers on these effects (Chu, online 2003)

The current research with regards to military oceanography in South Africa is basically summarised in table 2.2, with specific references to modelling later in this chapter. The Institute for Maritime Technology in Simon's Town thus primarily cover military oceanography requirements for the SAN, as directed by the hydrographer of the SAN.

3.3 Warfare in the Littorals

"*It is too late to learn the technique of warfare when military operations are already in progress*" – General Aleksei A. Brusilov

(as quoted by Rosenberg & Anderson, 2001)

Warfare in the littorals is a battle to be won by the side with the best and most reliable information at hand. An environmental assessment must be made and decisions on tactics should follow on that. These factors all contribute to the operational and overall efficiency of the attempt to conquer the enemy.

Only so much real-time information can be available when planning an assault abroad. Proceeding with an offensive when your environmental information is lacking depth, can have severe results. Such was the case with an amphibious group attempting a landing at Tarawa in 1943 when an unanticipated low water over the barrier reef grounded an entire wave of landing craft, hundreds of yards short of the beach (Davis IV, 1995).

The major threats in the littorals identified by Chu and Haeger, are those posed by diesel submarines and sea mines. They also make reference to two important concepts supporting their statement. Firstly, the fact that sensors on sophisticated weapons like torpedoes, designed for blue-water warfare, are not designed to acquire targets in a reverberation-crippled environment. Secondly, although sea mines are not as sophisticated as many other weapon systems, they have been the number one cause of US Naval casualties since the end of WWII.

How can this information gap be breached in this modern technological era? The answer lies in prediction. Although some might regard the littoral zone as a chaos zone, prediction is not impossible. Numerical modelling of coastal environments has shown great successes in search and rescue operations, oil slick pollution control, ect. Why not apply it for military purposes?

3.4 Introduction to Operational Oceanography and Modelling

Operational Ocean forecasting has taken a turn since the Cold War ended in 1991 and the modelling of the littorals has become important in the new era of brown-water warfare. Burnett defines operational oceanography as being "a compromise between the scientifically possible and the operationally necessary and practical" (Burnett et al., 2002).

Ocean modelling is on an ever-growing development path striving for perfection as modern technology and processing power expand in their abilities. The constraints to any coastal country's ability to do ocean prediction lies in the availability of capable personnel, proper communications capabilities, and computational resources available (Burnett et al., 2002). One of the major problems when modelling waves (wind waves) in shallow water is the lack of data from measurements. Contrary to deep-water, waves in shallow and very shallow waters are governed by bottom friction. Wind generated growth, propagation, non-linear interactions, energy decay and possibly white-capping enhancement, are all linked to how the waves interact with the bottom (Padilla-Hernández et al., 2001).

Due to the unpredictability and lack of information in the littorals and near coastal area, the best way to be able to make accurate predictions, is to model known littoral areas and compare model outcomes with previously unknown modelled areas. Modelling in a military context does not only imply offensive or defensive scenarios, but also support scenarios like search and rescue and damage control.

3.5 Modelling Overview

3.5.1 Historic Overview

Fundamental studies of water waves were successfully developed in the 19th century, but the modern studies of ocean surface waves only started in the 1940s, earmarked by the studies of Sverdrup and Munk in 1947 (Mitsuyasu, 2002). One of the most important points from their study was the introduction of the concept of energy balance in a wave system to understand the wave evolution. The energy balance equation also forms the basis of the model used in this study, as will be seen later.

Mitsuyasu, in his historic overview of the study of ocean surface waves, divides the problem areas of the (wind waves) study into six topics:

- Generation mechanism, including the generation of initial wavelets and the energy transfer from the wind to the waves;
- Statistical properties, including the wave spectrum;
- Non-linear properties, including the non-linear interaction among spectral components, wave instability and wave breaking;
- Laboratory and ocean experiments;
- Air-sea and wave project, and
- Wave forecasting (methods).

Of these six topics, wave forecasting, of which wave modelling is a component, is today for civilian as well as military operations, of great importance. As mentioned before, the study of wave forecasting started just after WWII. In the 1950s, Bretschneider (1952 & 1958) and in the 1960s, Wilson (1961 & 1965) greatly improved the wave forecasting methods of Sverdrup and Munk (1947) (Mitsuyasu, 2002). Their revised forecasting method was thus called the SMB (Sverdrup, Munk, Bretschneider) method.

Numerical wave models were presented by Inoue (1967) and Barnett (1968) in the 1960s with further fundamental studies, such as wave generation mechanisms, non-linear energy transfer and energy balance equation (Hasselman, in Mitsuyasu, 2002). A French group, however, independently developed a wave model in the 1950s (Gelci, in Mitsuyasu, 2002).

Recent studies on the fundamental processes that control the energy source terms have supported the development of third generation wave models. Included in these are:

- The energy input from the wind;
- The non-linear energy transfer among spectral components, and
- Energy dissipation due to wave breaking.

Mitsuyasu, however, specifically states the fact that even in the most advanced third generation model, some of the energy source terms depend largely on empirical values. Further studies are thus needed to develop a more improved wave model. These research efforts are largely governed by financial and security principles and the economic world leading countries will have the motivation and advantage to further such research efforts.

3.5.2 South African Navy

This thesis is the first known ocean modelling done by a SAN uniformed member. The leader, however, in ocean modelling in South Africa is the CSIR, although not necessarily for the SAN. IMT has recently started to put together an OIS (Ocean Information System) exclusively for the SAN. The three broad categories covered, are Oceanography, Meteorology and the Seafloor. Some technology demonstrators used over the years, include a data contouring module and a 3D processing and visualisation module for seafloor information (Wainman, 2003). Work has started on producing MDD2000 (Maritime Data Display) in 2000, in order to upgrade the historic sound velocity profile package. This product has been upgraded and now also includes seafloor characteristics, linking with IMT's ray program SMOD (Sonar Model), which also consists of the TRAY (Tactical Ray Trace Model) and HRAY (Hugo Biermann Ray Trace Model). The impression is that the SAN is comfortable with this (MDD) system residing at IMT (Wainman, 2003).

3.5.3 United States Navy

The USN is the self-admitted leader in ocean modelling, generating vast data sets (i.e. the USN Tactical Environmental Data Server (TEDS)) of local and international oceans. They are currently using (or has under evaluation) 17 models (Burnett et al., 2002) for the modelling of various ocean components (see Table 3.1). They use two production centres for their modelling: FNMOC (Fleet Numerical Meteorology and Oceanography Centre) and NAVOCEANO (Naval Oceanographic Office).

Ocean Systems	Description	Data Assimilation and Models
OCEAN ANALYSIS	3-Dimentional Ocean Multi-Variate Optimal Interpolation System	OCEAN MVOI
	Modular 3-Dimentional Ocean Data Assimilation System	MODAS
OCEAN CIRCULATION MODELS	Upper Ocean Mixed Layer Forecast (global and fixed regions)	TOPS
	Deep Ocean Mesoscale Prediction (global)	NLOM
	Upper Ocean and Coastal Ocean Prediction (global initially)	NCOM
	Coastal Ocean Prediction (various fixed regions and nests)	SWAFS
	Rapidly Relocateable Ocean Prediction (regional and nests)	ReloPOM
	Advanced Hydrodynamic Circulation Model for Shelves, Coasts, and Estuaries	ADCIRC
WAVE, SURF AND TIDE MODELS	Third Generation Wave Action Model (global and regional)	WAM
	Wave Watch III – Next Generation Wave Model (global)	WW3
	Near Shore Spectral Wave Model (regional)	STWAVE
	Rapidly Relocateable Navy Standard Surf Model	NSSM
	Rapidly Relocateable Tidal Model	PC TIDES
ICE MODEL	Polar Ice Prediction System (Northern Hemisphere to 30° N)	PIPS
ATMOSPHERIC MODELS	Atmospheric Prediction System (global)	NOGAPS
	High Resolution Atmospheric Prediction System (regional and nests)	COAMPS
	Tropical Cyclone Model with Imbedded Nests	GFDN

Table 3.1: USN Models: Available or undergoing operational evaluation. (Burnett et al., 2002)

The USN has recently seen the advantage of having a model that is able to predict coastal conditions by integrating various sub-models into one. The IOPS (Integrated Ocean Prediction System) has been developed for accurate prediction of surf processes with the aim at optimising effective amphibious landings. This wave-tide-surf-model provides integrated wave information from deep to shallow water into the surf zone (Allard et al., 2002). The model comprises the following four components of which all but one are described in table 3.1.

- Wave Action Model (WAM)
- Two shallow water wave models:
  - Steady state model (STWAVE)
  - REFraction/DIFraction model (REFDIF)
- Two tidal models
  - ADCIRC
  - PC TIDES
- Navy Standard Surf Model (NSSM)

The IOPS (a component of the Rapid Ocean Analysis Modelling Evaluation Relocatable System (ROAMER)) is designed to provide the USN with the capability to set up, run and monitor model performance using a graphical user interface (GUI) (Allard et al., 2002). IOPS is, however, a relatively new model which has been delivered to NAVOCEANO in December 2001 and evaluation of the system only started in January 2002 (Allard et al., 2002). The future plans (according to Allard et al.) include the integration of the SWAN (Simulating WAves Nearshore) model into the IOPS. The reason being that SWAN includes improved approaches for wave propagation and the ability to operate efficiently in very fine grid meshes (order 100 m or less). A further motivation is that SWAN is a full plane model including capabilities for onshore and offshore winds and waves, having both time dependant and steady state modes. The ultimate goal of the USN is to provide situational awareness of the littoral and surf environmental conditions to the war fighter, on demand (Allard et al., 2002).

3.5.4 Other Models (non-Military Applications)

The prediction of variations in sea level and sea-state is very important for those living near, making their living from or working on, the sea. Modelling of tides, surges and waves thus become important also to the non-military community. In a paper by Flather, such operational systems in northwestern Europe is reviewed (Flather, 2000). EuroGOOS (European Global Ocean Observing System) sponsored a survey in which up to 30 operational models were found, only covering the southern North Sea. Of these, approximately half were wave or tide-surge/current models (Davies, in Flather, 2000).

3.5.5 Operational Systems: Northwest Europe and Other NATO Countries

The first true spectral mode wave-forecasting model was probably the P-T-B directional spectral model implemented at the Fleet Numerical Oceanography Centre (FNOC, now FNMOC) in 1973 (Cox & Cardone, [online]). By the time of the SWAMP model exercise, most of the participating models were used to make real time wave forecasts. These include: MRI (Japan), NOWAMO (Norway), GONO (The Netherlands), BMO (UK) and HYPA (Germany). The WAM group's mission was, however, to develop a model in time to be ready to assimilate data from the ERS satellite, which was to be launched in the early 1990s. Subsequently, most major governments adopted models like WAM and WAVEWATCH-III for global wave prediction (Cox & Cardone, [online]). Although WAVEWATCH-III, developed at NOAA/NCEP, follows on its predecessors, WAVEWATCH-I was developed at Delft University of Technology, and WAVEWATCH-II at NASA. It, however, differs from its predecessors on all the important points of the model (Tolman, [online]).

Table 3.2 lists countries in northwestern Europe as well as other NATO countries involved in operational oceanographic models, which at the time of this study, are used for wave prediction.

Country	Operational Model(s)	Characteristics
Norway: Norwegian Meteorological Institute (DNMI)	WINCH (replaced by WAM in 1999)	Wave Model (WAM) simulates wave states from wind
Denmark: Danish Meteorological Institute (DMI)	None WAM-cycle4 expected operational from end of 1999	(see previous)
Germany: Deutscher Wetterdienst (DWD)	HYPA HYPAS REFRAC WAM K-Modell	Hybrid-parametric spectral wave model for shallow waters (sea level can change) Decoupled spectral wave model for refraction in extreme shallow waters (see previous) Spectral wave model for coastal areas
Baltic Collaboration: Sweden, Finland, Poland, Germany and Denmark	HYPAS	(see previous)
Belgium: Afdeling Waterwegen Kust (AWK) & Management Unit of the North Sea Mathematical Model (MUMM)	HYPAS and developed refraction module	(see previous) Accounts for water depth changing with time due to tide and surges
United Kingdom: UK Meteorological Office	2nd generation wave model based on Golding and updated by Holt	Include shallow water physics in depths less than 200m, run globally and regionally
Ireland: Met Éireann	WAM	(See previous)
France: Météo France	VAG VAGATLA VAGMED	Deep water, 2nd generation 'couple discrete'

Spain: Clima Marítimo	WAM WAVEWATCH PROPS	(see previous) Receives boundary conditions from WAM Phase-averaged monochromatic wave propagation
Portugal: Instituto Superior Técnico (IST)	none	
Netherlands Koninklijk Nederlands Meteorologisch Instituut(KNMI)	NEDWAM SWAN	Limited area version of WAM Comparing and coupling with NEDWAM, under consideration

Table 3.2: Operational wave models in north-western Europe and other NATO countries. (Flather, 2000 and GKSS Institute for Coastal research, [online])

3.5.6 Nearshore Wave Simulation

For the purpose of this study, the SWAN model was used as operational model for wave forecasting in a case study to investigate the military implication. This model will thus be described in short below.

Swan is a third-generation wave model, developed by Delft University of Technology in the Netherlands. It can be used to simulate the evolution of random, short-crested wind-generated waves in coastal regions, channels, barrier islands with tidal flats, lakes, tidal inlets, and estuaries, and is the successor to the second-generation HISWA model (SWAN Manual, 2000). SWAN also has the ability to couple with other modules of Delft3D, being:

- Delft3D-Flow (wave driven currents, enhanced turbulence and bed shear stress) and;
- Delft3D-Mor (stirring by wave breaking).

Visualisation of results is being done with Delft-GPP (general post-processing program).

3.6 SWAN Usage

SWAN is being used by more than 100 international users and is well documented. Amongst other, it is also being used in the Northern Gulf of Mexico Littoral Initiative (NGLI) where other wave models will be run separately for comparison with the SWAN model. These models include: WAM, REF/DIF, STWAVE and NSSM (NGLI online, 2003)

The NGLI clearly indicates what SWAN does or does not account for. According to the NGLI, SWAN does account for the following:

- Wave propagation in time and space, shoaling, refraction due to current and depth, frequency shifting due to currents and non-stationary depth
- Wave generation by wind
- Three and four-wave interactions
- Whitecapping, bottom friction, and depth-induced breaking
- Wave induced set-up
- Propagation from laboratory up to global scales
- Transmission through and reflection from obstacles.

SWAN does not account for the following:

- Diffraction
- Scattering reflections

3.7 SWAN Model Basic Description

The following description of the SWAN model comes from the developers of the model and an article published by them in the *Journal of Geographical Research* (Ris et al., 1999):

The basic equation used in the SWAN model, is the action balance equation:

$$\frac{\partial}{\partial t}N + \frac{\partial}{\partial x}c_x N + \frac{\partial}{\partial y}c_y N + \frac{\partial}{\partial \sigma}c_\sigma N + \frac{\partial}{\partial \theta}c_\theta N = \frac{S}{\sigma} \ ,$$

where $N(\sigma,\theta,x,y,t)$ is the action density as a function of intrinsic frequency σ, direction θ, horizontal coordinates x and y, and time t, and;

where $S(\sigma,\theta,x,y,t)$ [$= S$] is a source term representing the effects of generation by wind, dissipation and non-linear wave-wave interaction.

The terms in the equation represents the following:

$\frac{\partial}{\partial t}N \rightarrow$ The local rate of change of action density in time

$\frac{\partial}{\partial x}c_x N$ and $\frac{\partial}{\partial y}c_y N$ $\rightarrow$ propagation of action in geographical x,y space respectively, with propagation velocities c_x and c_y.

$\frac{\partial}{\partial \sigma}c_\sigma N \rightarrow$ shifting of the relative frequency due to variations in depths and currents (with propagation velocity c_σ in σ space)

$\frac{\partial}{\partial \theta}c_\theta N \rightarrow$ depth and current-induced refraction (with propagation velocity c_θ in θ space),

where the expressions for these propagation speeds are taken from linear wave theory.

The following table (table 3.3) indicates which expressions, and references, were used in the model:

Remarks	Expressions	Reference
This set of formulations is identical to the one that is used in cycle 3 of the Wave Model (WAM)	Deep and intermediate-depth water	Booij et al., 1999
	Wind input and whitecapping	Komen et al., 1984
	Quadruplet wave-wave interactions	Hasselman et al., 1985
	Bottom friction	Hasselman et al., 1973 Joint North Sea Wave Project (JONSWAP)
	Triad wave-wave interactions	Eldeberky, 1996
	Depth induced wave breaking and spectral version of the model	Battjes and Janssen, 1978
	Numerical scheme	Booij et al., 1999

Table 3.3: Expressions used in SWAN and references as described by Ris et al., 1999.

3.8 Motivation for Using SWAN

The SWAN model was selected as operational model in this study for the following reasons:

- It is a widely used international model with experts in South Africa at the CSIR and the Department of Applied Mathematics at the University of Stellenbosch.
- From a military oceanographic perspective, it is a state of the art model only starting to be integrated in countries like the USA.
- Validation of the model in the South African coastal zone should be extended, as special cases exist along the coast of South Africa, with special reference to the west coast (Van der Westhuysen, 2002).
- In the light of the beach landing exercise done by the US Navy in 2001, this model has not yet been applied in the St Helena Bay area and deductions made from a military perspective.

The SWAN model will thus be applied to the St Helena Bay area with special reference to the beach area between Laaiplek and Dwarskersbos. This area will be discussed in the next chapter, after which three case studies will be covered in chapter 5 of this thesis.

CHAPTER 4

RESEARCH AREA

4.1 Introduction

This section will describe the research area (near-shore part of the littoral) used in the SWAN model case studies. The location described provides a feeling for what the littoral profile looks like and thus the wave conditions that can be expected in this specific area. This information will then set the background for a comparison with the outcome of the model.

4.2 Location

St Helena Bay is situated at the West Coast of South Africa, facing a west-northwest direction. This area was selected against the background of Operation LAUREL (Sverdloff, 2001) when the *USS Gunston Hall* participated in a combined exercise with the SA Navy. A fictional humanitarian relief training exercise was established in the St Helena Bay area and amphibious landings were conducted. The physical environmental data was limited, as it would be in any real-time situation. Navigational charts were used for bathymetry data, and some of the ocean areas had well been surveyed in the past. The area near and around Laaiplek had been surveyed in 1923 by lead line, but a new survey was done in 2001 for the above-mentioned operation.

Figures 4.1 (from SAN 1009) and 4.2 (from SAN 4) indicate the research area; both being copies from navigational charts supplied by the Hydrographer of the SA Navy.

Figure 4.1: Part of chart SAN 4 indicating St Helena Bay (black box) on the West Coast of South Africa (with permission from SAN Hydrographer).

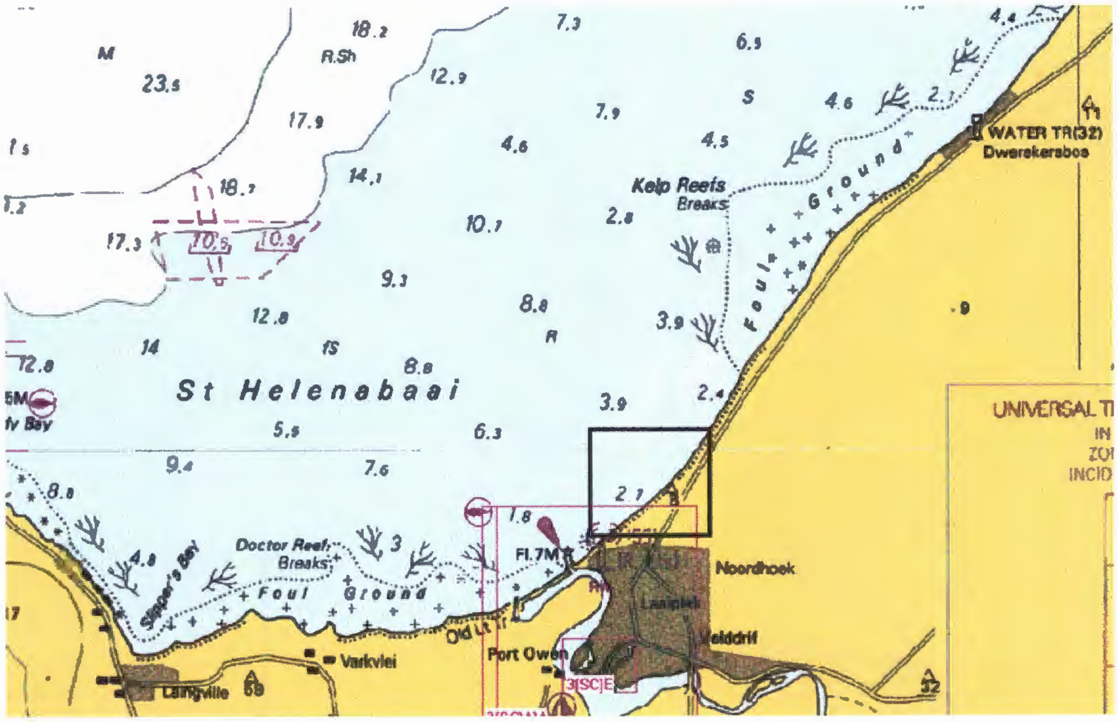

Figure 4.2: Part of chart SAN 1009 with St Helena Bay, and the approximate surveyed area for Operation Laurel indicated (black box) (with permission from SAN Hydrographer).

4.3 Littoral Profile

The Hydrographic survey ship SAS PROTEA, specifically surveyed the exercise area (indicated in fig 4.2) in St Helena Bay for Operation Laurel before it was conducted. All the preparative work as well as the survey was done in the period between 15 and 24 October 2001.

The following general (relevant) findings about the profile of the area was recorded in the survey report (Survey report 2/01, Capt(SAN) A. Kampfer, 2001):

Area limits and description: The area is bordered by the following parallels and meridians: 32° 43,7' S and 32° 45,9' S parallels and 18° 08,4' E and 18° 10,7' E meridians. This yields a block of 2,20 NM by 2,19 NM, covering a coastal length of 2 NM with the furthest offshore point being 2 NM seaward.

4.3.1 Physical Findings

a. Sediment: The seabed consisted primarily of sand and broken black mussel shells. Sampling on the beach rendered no rocks.

b. Coastline: The coastline consists of long beaches of sand and broken shell, with small dunes covered in vegetation.

c. Sea and swell: Sea and swell conditions are mostly affected by wind. The surf zone is approximately 4m and also affected by wind, with small breakers close to the beach.

d. General: After investigation of the seaward approaches, there were no dangers or significant features found to be in the way and the nature and composition of the beach was found trafficable for wheeled vehicles.

4.3.2 Own Observations

The abovementioned observations only apply to the small area surveyed for the purpose of Operation Laurel. A larger stretch of sandy beach is, however, considered to provide a more realistic result of wave climate influence in the bay. The beach area from Dwarskersbos to the Berg River mouth was physically investigated, and observations were noted and plotted by handheld GPS. The South African Air Force took a sequence of aerial photos on 5 September 2003 of the mentioned area at a height of 1000 ft, on request. These photos were taken between 1115AM and 1118AM (SAST) and high water was at 1120 (in Saldanha) at a height of 1,33 m above CD (Chart Datum). This date incidentally coincides with the date of the storm of 2001 – one of the case studies in this thesis.

The following table indicates own observations made in October 2003 just after spring low on the day, indicating position and corresponding aerial photo (observation points marked by arrows).

Latitude	Longitude	Observation	Photo
32° 41,45' S	18° 14,0' E	(Next to Caravan Park): Broken black mussel shells, medium to fine sand	Photo 1
32° 41,99' S	18° 13,29' E	(Southern entrance to town): Sandy cusps with broken shell ridges, sand has black colour	Photo 2
32° 43,15' S	18° 11,76' E	(Conspicuous rock opposite reef): Sandy cusps with broken shell and some pebbles	Photo 3
32° 45,16' S	18° 10,12' E	Beach access point 600m from beacon: Larger cusps, less shell, no visible pebbles, sand	Photo 4
32° 45,98' S	18° 09,02' E	Opposite old jetty: No cusps, lighter coloured sand	Photo 5
North of Dwarskersbos		More sandy beaches (according to residents)	None

Table 4.1: Observations made at various positions between Dwarskersbos and Laaiplek.

Photo 4.1: First observation: Dwarskersbos Caravan Park.

Photo 4.2: Second observation: Southern entrance to Dwarskersbos.

Photo 4.3: Third observation: Conspicuous rock opposite reef.

Photo 4.4: Fourth observation: Beach access point (600 m from beacon).

Photo 4.5: Fifth observation: Opposite old jetty.

The selection of the five observation points were made according to the following criteria:

Observation 1:	Northern boundary of area of concern.
Observation 2:	Ad hoc.
Observation 3:	The reef is where wave characteristics are expected to vary.
Observation 4:	Beach access road is close to northern boundary of Operation Laurel survey area. The beacon forms the centre of the area.
Observation 5:	Near southern boundary of area of concern.

The five observation points are indicated in figure 4.3, clearly showing the positions between Dwarskersbos and the Berg River mouth at Laaiplek, on a smaller scale.

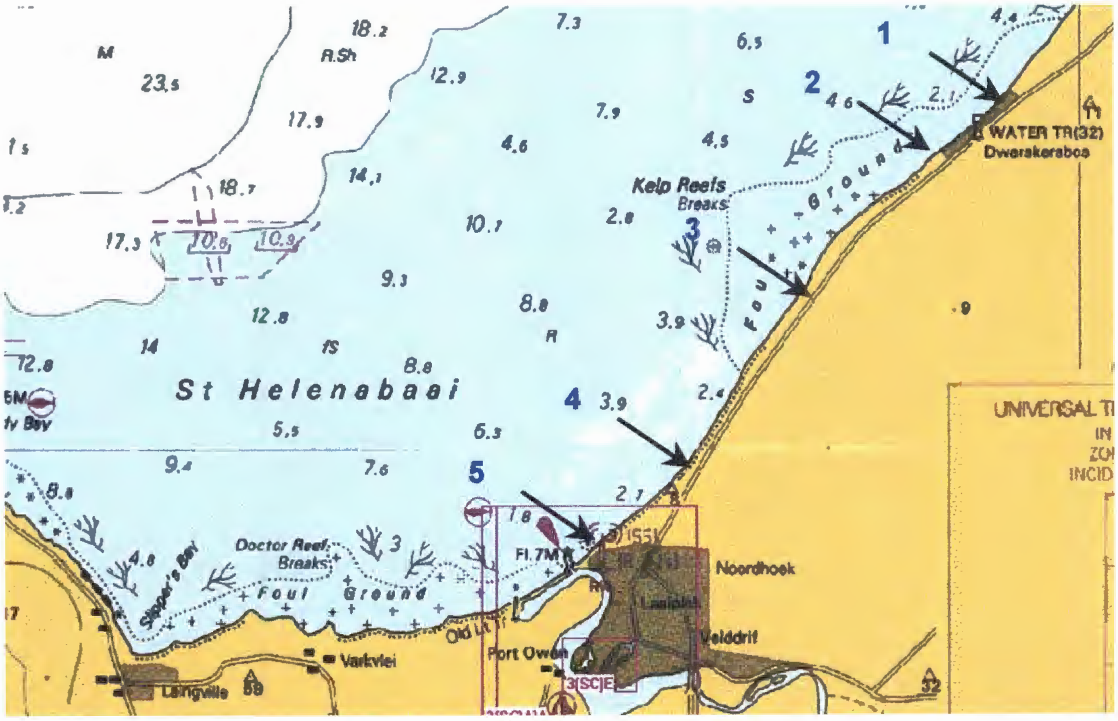

Figure 4.3: Sample points in St Helena Bay as indicated by photos 1 to 5.

The beach slopes were physically measured at all five observation points by means of a hand-held stick, level and protractor. These measurements were taken at the high-water level and varied between 10° and 20° (not measured to precision). Smaller gradients were measured at point 1, points 2, 3 and 4 correlated well and maximum values were measured at point 5.

Wavelengths in the breaker zone (according to photo 1) are estimated to be approximately 45m (compared to a measured distance on land). Using the graph in figure 4.4 (Brown et al., 1999), with an average beach slope of ± 15° and grain size between medium and coarse sand (as observed), a wave height at the breaker zone of between 0,4 m and 0,6 m are expected.

This beach is thus also classified as a reflective beach type, which, according to Brown & McLachlan, confirms the cusp formations observed (Brown & McLachlan, 1990). By using the beach slope and grain sizes, the beach between the Berg River mouth and Dwarskersbos can be classified as being *protected* to *moderately protected* (Brown & McLachlan, 1990).

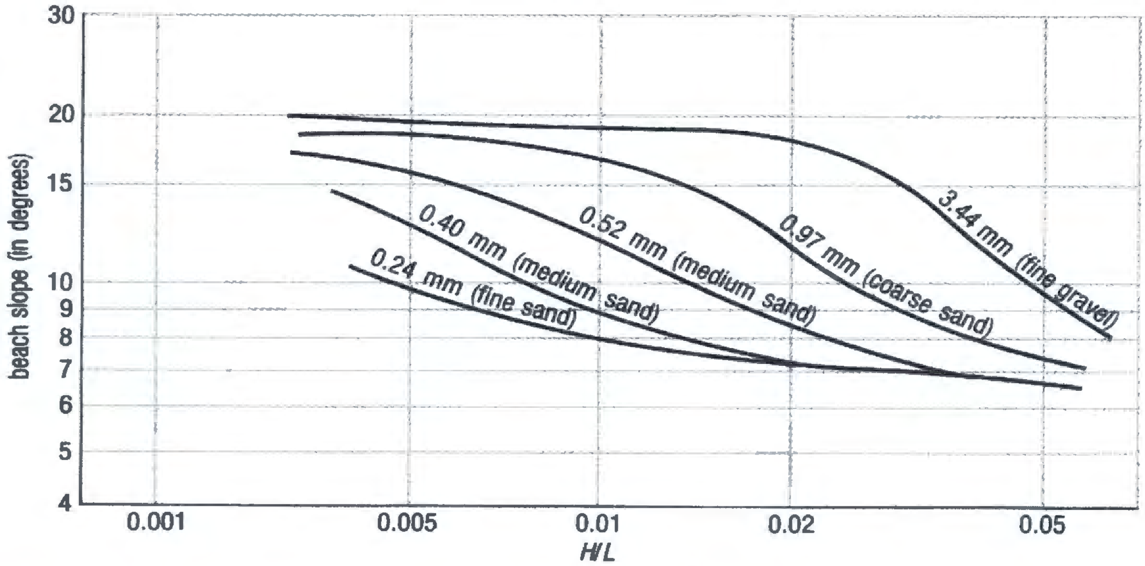

Figure 4.4: Beach slope against wave steepness for specific grain sizes. (Brown et al., 1999)

4.4 Weather Patterns and Wave Climate

The wave patterns around southern Africa are influenced by the weather systems, and thus wind conditions, experienced in the southern hemisphere. The location of the research area can be seen to be just south of the Horse Latitude (30° S) where high-pressure systems are generated by the descending air from the Hadley cell. South of 30° the surface winds of the Ferrel cell form the western trade winds, which spirals easterly around the globe. Disturbed air in the Ferrel cell causes low-pressure systems in the south Atlantic. These low-pressure systems, with their associated cold fronts, thus move from west to east in the Ferrel cell. These depressions are the main cause for large wave generation along the South African coastline (Rossouw, 1989).

The six-cell model for air circulation around the globe, however, is an average of airflow taken over some years. These cells, of which three are in the southern and three in the northern hemisphere, are not symmetrical around the geographical equator, but rather around the meteorological (or thermal) equator. The position of the meteorological equator and the Inter-Tropical Convergence Zone (ITCZ) generally coincide and changes with the seasons (Garrison, 2002). This implies the movement of the pressure systems and cold fronts to the north in the southern winter. An increase in storm severity and thus wave height conditions can be expected during these southern winter months. Occasional northerly movement does, however, occur during the southern summer season, also producing occasional high wave conditions.

These cold fronts pass the southern tip of Africa regularly with intervals of 3 to 5 days (Rossouw, 1989). They move rapidly on their eastern bound path, at speeds in access of the group velocity of the waves. The changing wind direction associated with a passing cold front system (NW through SW to SE) together with the speed of the cold front system, results in duration limited wave conditions and fully developed seas seldom occur (Rossouw, 1989). Figure 4.5 indicates the typical pattern of pressure distribution (left) and basic air mass movement (right) over Southern Africa in the summer, and figure 4.6 indicates the same patterns during winter.

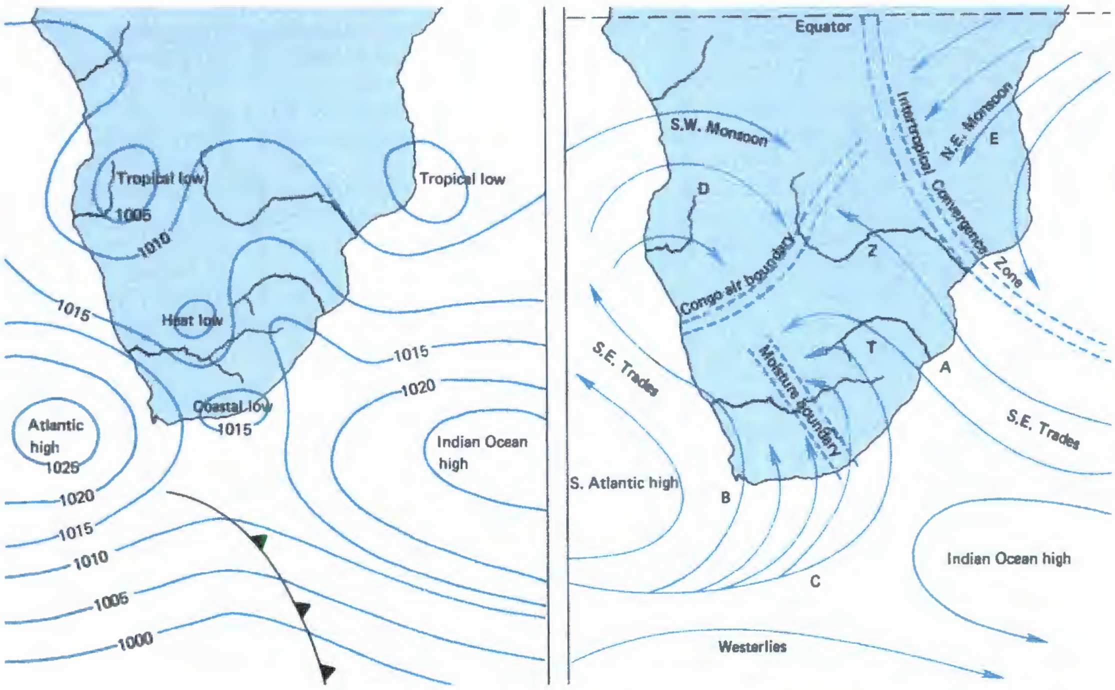

Figure 4.5: Pressure patterns and air mass movement over Southern Africa in summer. (Van Heerden & Hurry, 1987)

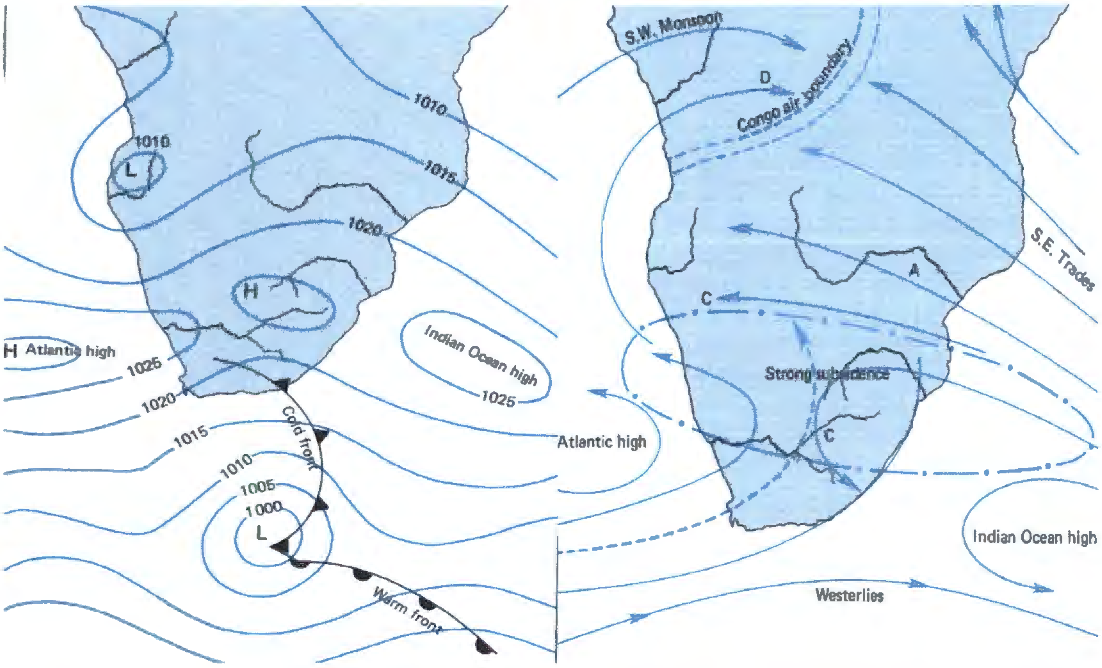

Figure 4.6: Pressure patterns and air mass movement over Southern Africa in winter. (Van Heerden & Hurry, 1987)

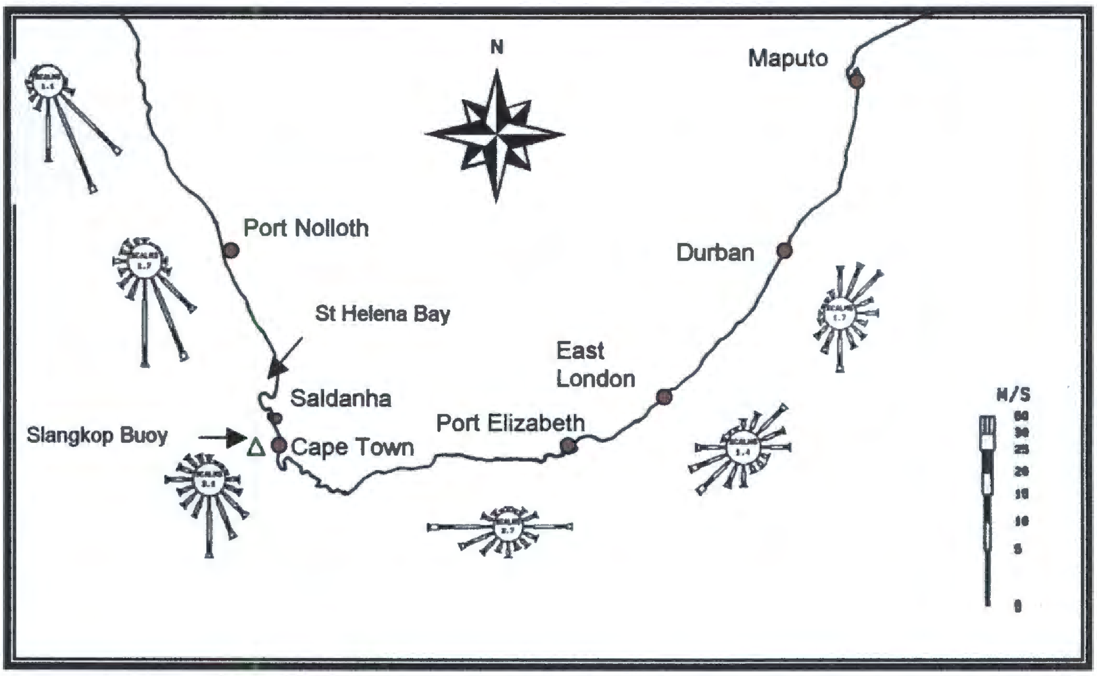

Figure 4.7: Wind climate around the Southern African coast based on VOS data between 1980 and 2000. (Van der Westhuysen, 2002)

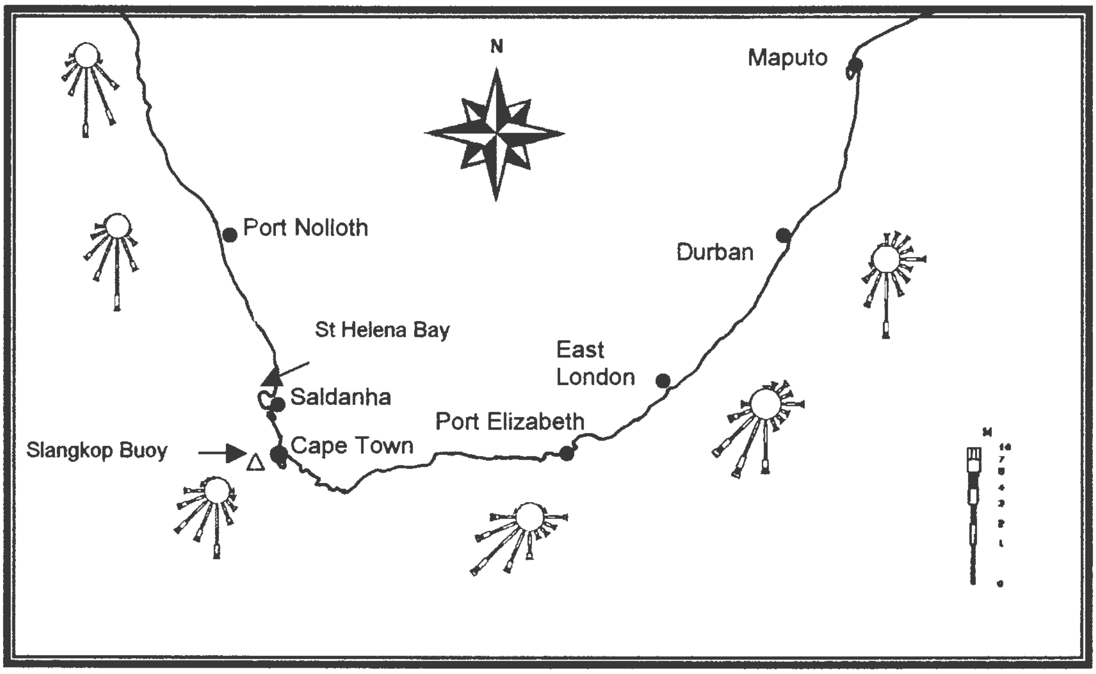

Figure 4.8: Offshore wave climate around the South African coast, based on VOS data between 1980 and 2000. (Van der Westhuysen, 2002)

In figure 4.7 it can be seen from observed (VOS) data that the primary wind direction is from the southeast with a uniform distribution from southwest to northwest. The position of the wind rose is also close to the Slangkop buoy, from which the source data for wave modelling was obtained. The general wave direction can thus be appreciated to approach the continent approximately from the southwest. In figure 4.8 it is shown that the general wave direction is from the southwest with a strong southerly component. It will be seen in chapter 5 of this thesis, the data analysis, that approaching storms have the tendency to cause waves to alter their approach to the continent to come from a more westerly direction.

CHAPTER 5

DATA AQUISITION AND ANALYSIS

5.1 Introduction

Certain initial data was needed to set up the model, as well as to be able to prepare the wave data to enter into the model once it is set up. The setting up of the model required digital values for land boundaries and bathymetry in the Local Ordinate (LO) reference system. The wave data was required in a digital format, applicable to the analysing program in use i.e. a spreadsheet, and was thus imported as text files.

5.2 Data acquisition

The initial data obtained for the study and the source of the data, is summarised in the following table:

Data type	Source
Wave T_p, H_{mo} and direction (buoy)	CSIR (Slangkop wave-rider buoy)
Wave T_p, H_{mo} and direction (VOS)	CSIR (SADCO)
Bathymetry	Digitised (at CIGCES) from SAN charts
Coastline	Digitised (at CIGCES) from SAN charts

Table 5.1: Data used in the study and sources.

All the data in table 5.1 was considered for the model, and the wave data forms the most important part. The two sets of wave data, from the buoy and VOS, were subjected to a comparative statistical test as discussed later in this chapter. The coordinates of the digitised bathymetry and coastline data had to be adjusted for the model as discussed later in this chapter under the grid positioning and limitations.

5.3 Wave Data

Two sets of wave data were requested and received from the CSIR. Due to the uniform wave climate from the SW (Rossouw, 1982), and the shortage of wave data at or near the research area, data sources open to the SW only, were considered.

The two data sources used, were VOS data and wave data from the Slangkop wave-rider buoy. The VOS data was selectively sorted to include only the area west of Cape Point.

The VOS data group contained historic data reaching back to 1960. Due to the recent dates in the buoy data group, no VOS data before 2000 was considered for analysis. A further refinement in data selection is explained in the next section where a comparison between the VOS and buoy data is made. Such a comparison was considered to investigate the accuracy of the VOS data for use in the model, which could influence the outcome. Rounding off, being a natural human tendency, is the major concern.

5.4 Analysis and Statistical Comparison: VOS and Slangkop Buoy Data

5.4.1 Introduction

Two groups of wave data were obtained from the CSIR in Stellenbosch. The one group consists of a wide spectrum of accurate wave data sets, which was generated by the wave-rider buoy off Slangkop (d = 80m since June 1994, sponsored by NPA (National Ports Authority) in Cape Town and Saldanha, and De Beers Namibia). The other data group is a compilation of wave data, as well as some meteorological data, obtained from Voluntary Observation Ships (VOS from the SADCO data base). Both groups of data were analysed and a comparison between applicable common components was made. The purpose of the comparison was to determine the credibility of the VOS data against the buoy data. All incomplete daily or hourly data sets were ignored in the analysis of both the VOS and the buoy data. The comparison between the two data groups was only done for the period of date overlap between the two groups. Although the buoy data was taken from 1 January 2001 to 30 April 2002, the only overlapping VOS data is from 4 January 2001 to 23 June 2001. The last mentioned period was thus used to make the comparison. Table 5.2 shows what initial analyses were made, but in the comparative study, it will be shown that only the data from the wave rider buoy was considered and graphically represented.

The atmospheric pressure from the VOS data was ignored, as no such data was acquired from the buoy and no indication was given to which level the individual barometers were calibrated.

Slangkop Buoy	VOS
Polar distribution H_{mo} vs Direction	Polar distribution Swell Height vs Direction
H_{mo} vs Date	Swell Height vs Date
T_p histogram	Swell Height histogram
H_{mo} histogram	Directional histogram
Directional histogram	Atmospheric pressure vs Date

Table 5.2: Data sets initially compared between the VOS and Slangkop buoy data groups.

5.4.2 Comparative Tests and Outcomes

A two-sample t-test assuming unequal variance was performed for both wave direction and wave height. This was done to determine whether a statistical meaningful difference exists between the Slangkop buoy data (population 1) and VOS data (population 2). The hypotheses were defined as (null hypothesis) H_0: $\mu_1 = \mu_2$ and (alternative hypothesis) H_a: $\mu_1 \neq \mu_2$. A significance level (α) of 5% was used. The outcome of the hypothesis testing was as follows (tables 5.3 and 5.4):

Wave Direction

Descriptive statistics:	Buoy	VOS
Observations	2705	316
Mean	222.8	210.6
Median	224	215
Standard deviation	21.0	54.8
Variance	442	3001
Min	157	10
Max	349.7	360

t-Test: Two-Sample Assuming Unequal Variances:	
Hypothesized Mean Difference	0
Df	326
t Stat	3.9
P(T<=t) one-tail	« 0.006
t Critical one-tail	1.6
P(T<=t) two-tail	< 0.02
t Critical two-tail	2.0

Table 5.3: Data summary and test results using Wave Direction.

Wave Height

Descriptive statistics:	Buoy	VOS
Observations	3162	316
Mean	222.8	210.6
Median	2.26	2.5
Standard deviation	1.0	3.5
Variance	1	12
Min	0.8	0.5
Max	9.9	37.5

t-Test: Two-Sample Assuming Unequal Variances:	
Hypothesized Mean Difference	0
Df	320
t Stat	-2.44
P(T<=t) one-tail	< 0.08
t Critical one-tail	1.65
P(T<=t) two-tail	< 0.02
t Critical two-tail	1.97

Table 5.4: Data summary and test results using Wave Height.

From the results it is clear that in both cases p-values of $p<0.02$ were obtained which indicate that H_0 is rejected. Hence the means of the two data sets differ significantly and a meaningful difference thus exists between the two data sets.

From the polar plot (figure 5.1), it can be seen that the visual observations were rounded, as all the plots lie exactly on the circular axis set. Another observation, which granted the VOS data not suitable for the model, was the mere fact that a visual observation of a swell height of 37,5m was made. The highest recorded wind driven deep-sea wave ever, was 34m (Garrison, 2002).

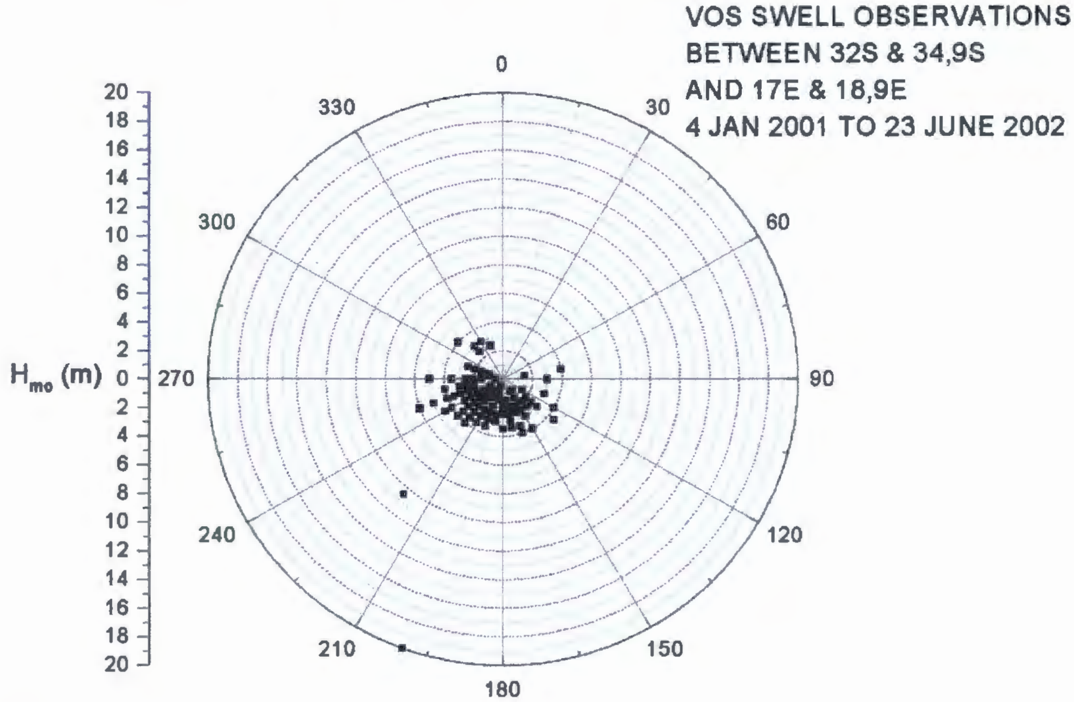

Figure 5.1: Directional wave distribution from VOS data.

Due to the difference between the two data sets, and the lack of wave period data in the VOS data group, it was decided only to use the Slangkop buoy data in the selection of a wave condition to enter into the model.

5.5 Input Data: Slangkop Buoy

The wave fronts approaching South Africa come primarily from a southwesterly direction as indicated in the polar plot in figure 5.2. The position of the wave-rider buoy (illustrated in figures 4.7 and 4.8) is such that it would not be significantly affected by land mass and the same wave characteristics could be assumed to approach the entrance boundary of the model. The entrance boundary of the model was therefore selected just north of the entrance to Saldanha Bay and modelled around to St Helena Bay.

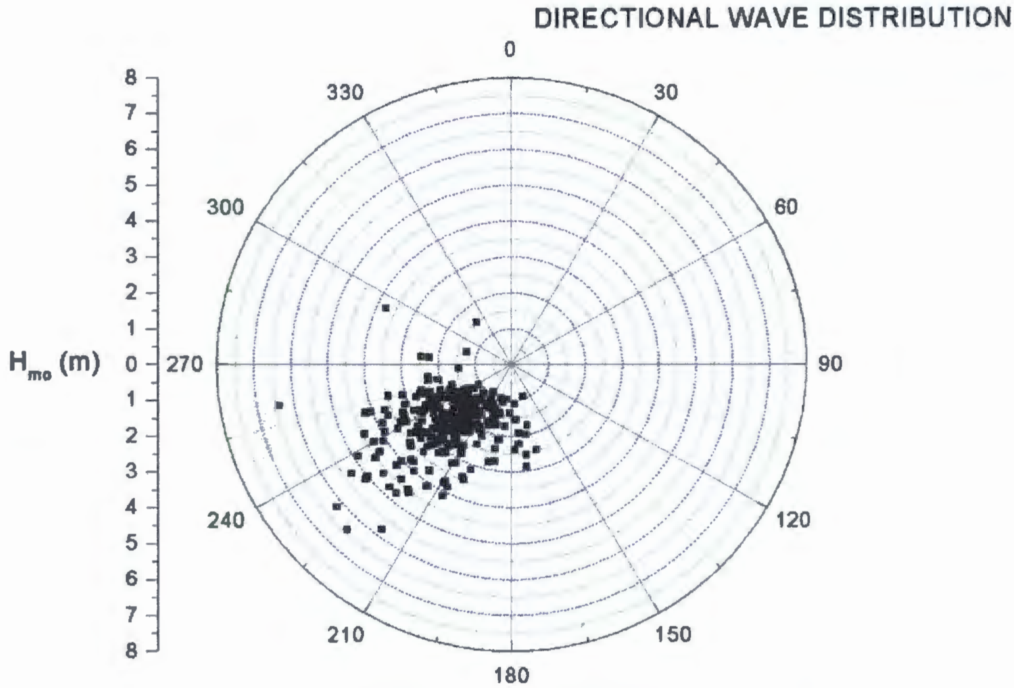

Figure 5.2: Directional wave distribution from Slangkop buoy data.

5.6 Buoy Data Analysis

In accordance with the required input parameters for the SWAN model, the significant wave height, peak period and directional distribution were analysed. The outputs of these data sets are graphically represented in figures 5.3 to 5.6.

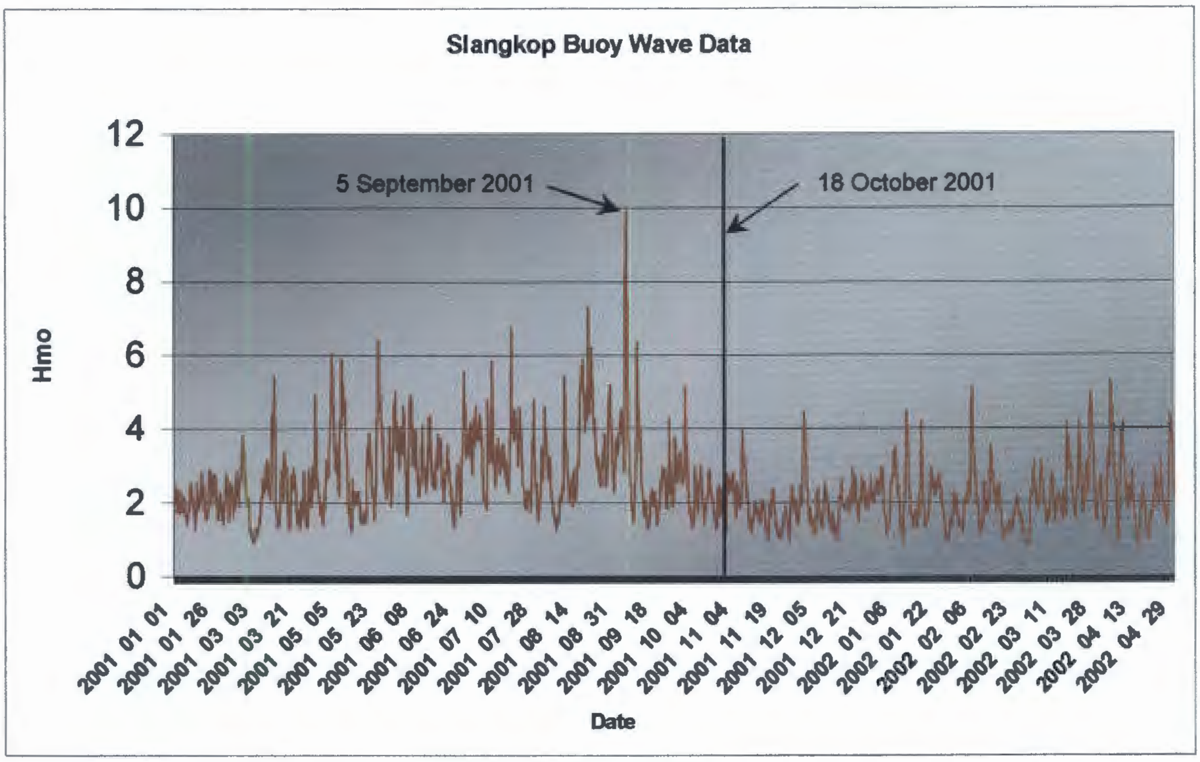

Figure 5.3: Wave height distribution recorded by the Slangkop buoy between January 2001 and April 2002.

In figure 5.3 an abnormal significant wave height of 9,88 m associated with a storm, can be seen as recorded on 5 September 2001 (indicated by arrow). The period of this wave was 18,1s, coming from a direction of 262°. This specific event is discussed and used in the SWAN model as one of the case studies in chapter 6 of this thesis. It can be seen from the various graphs that the wave direction changes from an almost westerly direction to a more south-westerly direction as this specific cold front moved passed the Cape during this storm event. In the other two case studies in chapter 6, the mode case and events on 18 October 2001 (indicated by a the vertical line) are considered, respectively. Wave directions are much more from the southwest and even south-southwest during these two events.

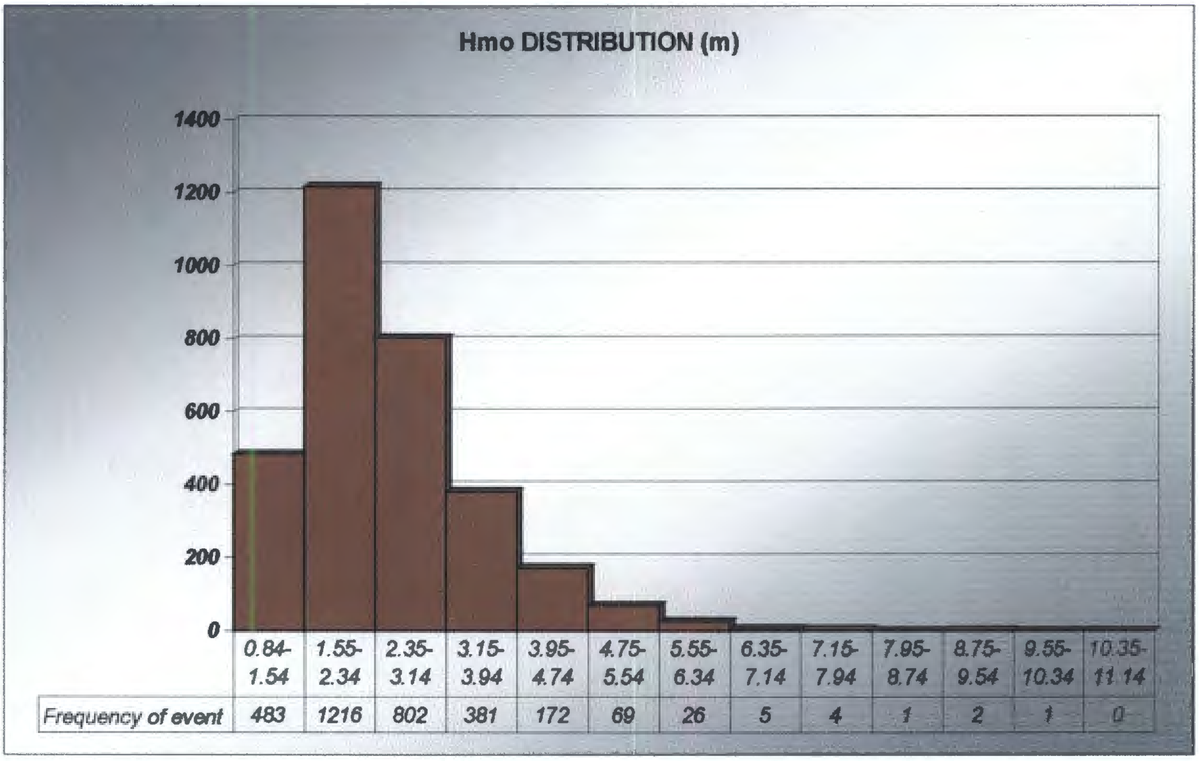

Figure 5.4: Histogram of significant wave height as recorded by the Slangkop buoy between January 2001 and April 2002.

The histogram of the significant wave height distribution indicated in figure 5.4, shows a positive skew distribution with the mode being between 1,55 m - 2,34 m (H_{mo}). In the case studies a value of 2,1 m (H_{mo}) is used. Figure 5.5 shows the mode of the peak period to be between 11,38s and 12,74s and a value of 12,5s was used in the case study. The wave direction histogram in figure 5.6 shows the mode to be between 225° and 241° and a value of 223° was selected for the case studies. All the values selected to enter into the model for the mode case study was done after further statistical analysis with the software package MSExcel™. A summary of the values used in the case studies is given in table 6.1.

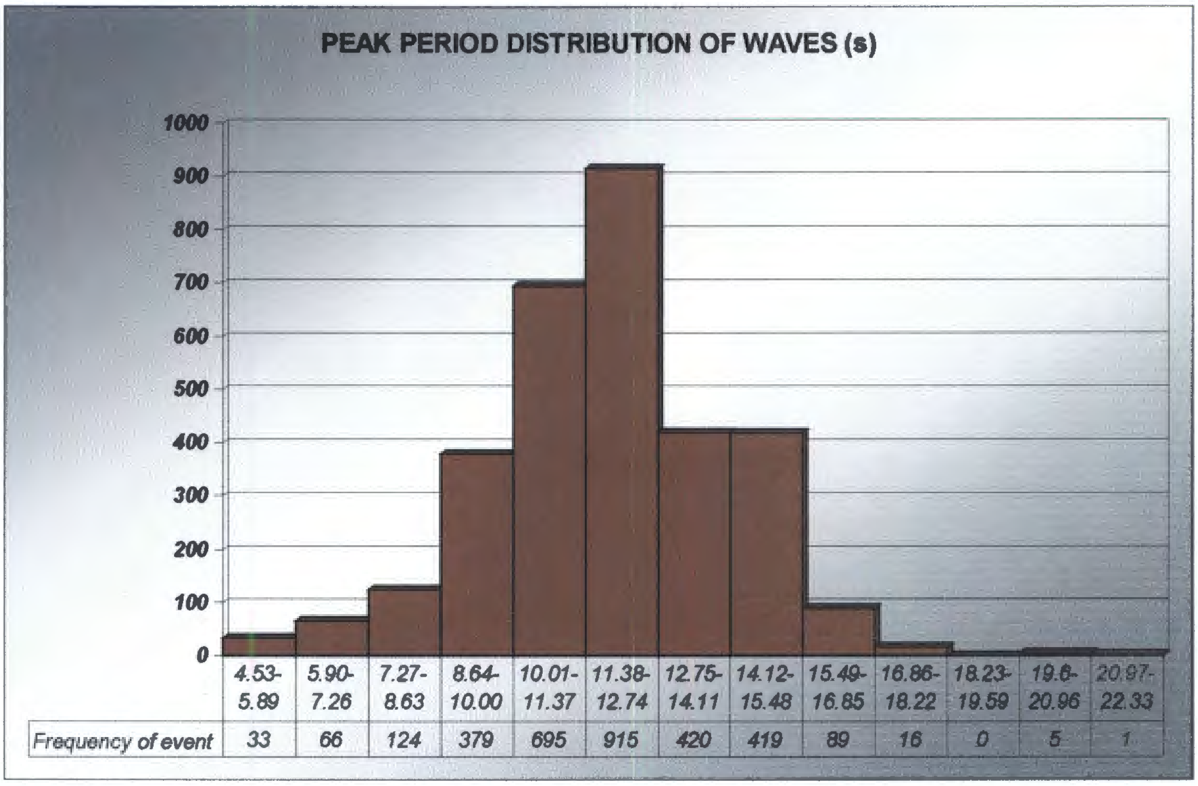

Figure 5.5: Histogram of wave period as recorded by the Slangkop buoy between January 2001 and April 2002.

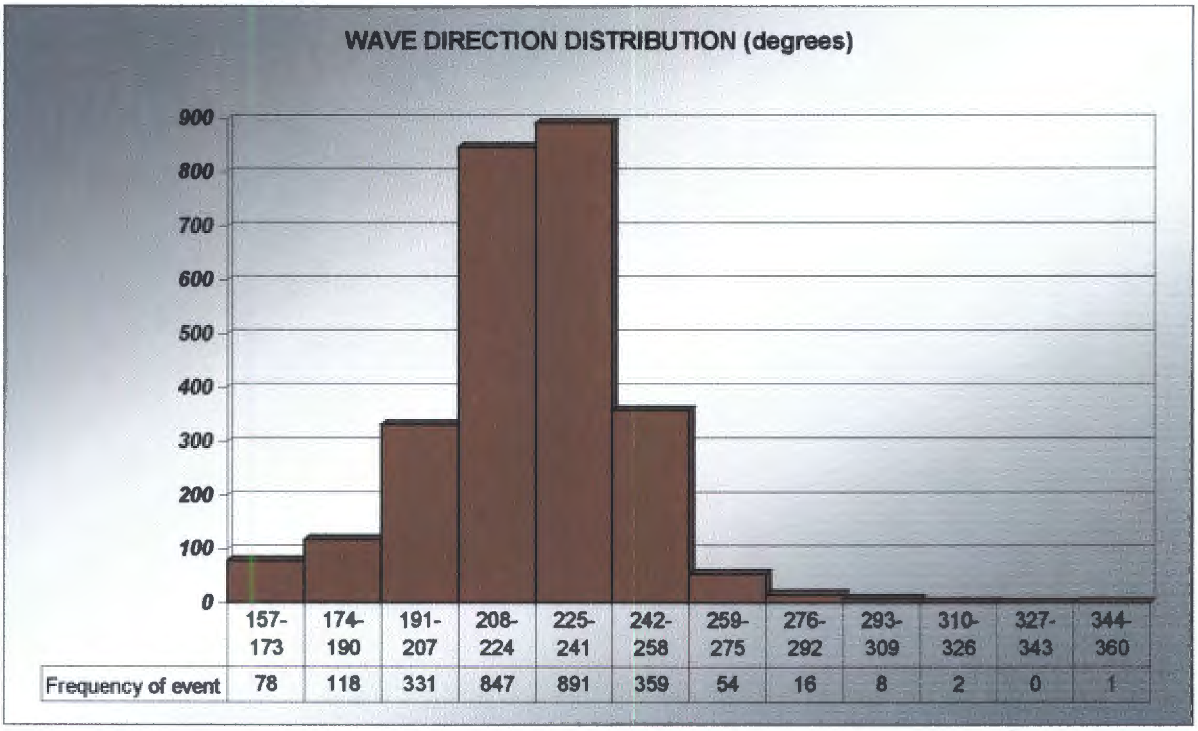

Figure 5.6: Histogram of wave direction as recorded by the Slangkop buoy between January 2001 and April 2002.

5.7 Land Boundaries and Bathymetry

No digital data for land boundaries or bathymetry was available from the hydrographer from the SA Navy, at the time of the study. The applicable navigational charts (SAN 118 and SAN 1009), were digitised and converted to the LO reference system with 19° E standard longitude (LO19). (The difference in amount of bathymetry readings is clearly visible due to the difference in scale between the two charts (figure 6.2)). The conversion of the charts to the LO projection, was assumed accurate as a uniform coordinate system was chosen and both charts were of the same projection (Clarke 1880). When using sequential charts in coastal research, the coherence of the projections could be one of the natural sources of error (Van der Wal & Pye, 2003). Two different individuals at the University of Cape Town's CIGCES (Centre for Interactive Graphical Computing of Earth Systems) centre digitised the two applicable charts respectively.

5.8 Conclusion

Although the VOS data was available from as far back as 1960, it did not satisfy the needs of this study as more accurate data was available from the Slangkop Buoy. The VOS data can, however, be used to verify some of the outcomes and to give a general idea of wave and wind conditions to be expected.

5.9 MODEL SETUP

5.9.1 SWAN as a part of Delft3D

The Delft 3-D modelling package consists of various components to set an integrated 2D/3D-modelling environment for:

- Hydrodynamics
- Waves
- Sediment transport
- Morphology
- Water quality
- Particle tracking for water quality, and
- Ecology

Of these, the Delft3D-Wave module is fully integrated with the other modules of the Delft3D modelling suite, and relevant data from one module can be used as input data for the next, as applicable.

SWAN forms part of the Delft3D-Wave component of the model and uses rectangular or curvilinear computational grids for calculations. It is a third-generation wave model, which computes random short-crested wind-generated waves in coastal and inland regions (online, 2003). The model has been tested extensively in the North Atlantic and was evaluated by using a case study done by Van der Westhuizen in Algoa Bay at the South African south coast (Van der Westhuizen, 2001).

The support tools required to produce the input files in the correct format and for visualisation respectively, are the following:

Delft-RGFGRID for the generation of the bottom grid (*.grd) file/s.
Delft-QUICKIN for generating the bathymetry (*.dep) file/s.
Delft-GPP (General Post processing Processor) for post processing visualisation

The bottom grid orientation was, however, considered with its south most boundary at the opening of the channel entering Saldanha Bay. This was done for the following two reasons: One being a limitation set by the computational grid orientation of the model, and the second being to negate initial wave refraction due to land interference.

Diagram 5.1 shows the data flow sequence for the model. Sample points of the bathymetry (from digitiser) is saved as a text (*.xyz) file and used in RGFGRID to generate the bottom grid. The coastline is imported as a text file (*.ldb) to assist with the grid orientation. The grid file is called up in QUICKIN with the bathymetry sample file. A polygon is drawn along the coastline to add a zero value boundary. Triangular interpolation was selected to generate a new bathymetry file (*.dep), which can be used as input file into SWAN. SWAN requires the bottom grid and depth file to set up the environment and define the input for the model.

After the model has run, the output can either be visualised directly in the GPP or used as input in other modules as required.

The sequence of data transport, is thus:

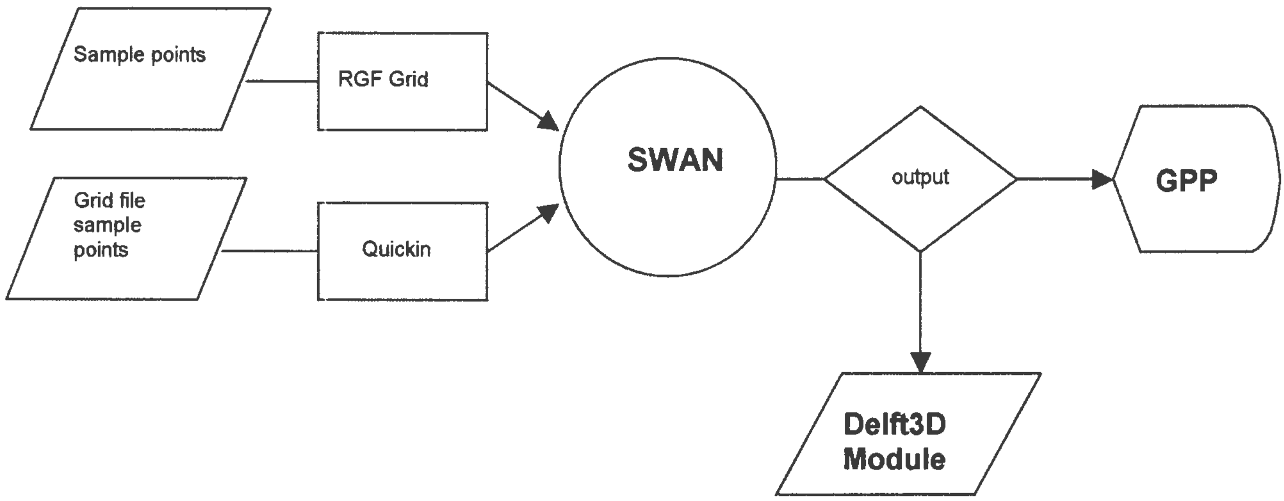

Diagram 5.1: SWAN data sequence.

5.9.2 SWAN Defined Input for Case Studies

This section will indicate which input definitions were used for the specific case studies. The input definition section of SWAN consists of the options as indicated, with specific actions taken for all the case studies:

Description	Optional
Flow	Ignored
Grids	See section 5.9.3
Time frame	Ignored
Tidal Information	Ignored
Boundaries	See section 5.9.5
Obstacles	Ignored
Physical Parameters	See section 5.9.6
Numerical Parameters	Defaults used
Output Curves	Not used
Output Parameters	Output on Large Grid

5.9.3 Grids

Three computational grids and three bottom grids were developed and selected to be of the same size respectively. Hence, each computational grid will have a fitting bottom grid. Figure 5.7 shows the layout of the three computational grids of which the orientation is described in table 5.5 (the grid values used are described later in this chapter). The large blue arrows indicate the incidence wave direction at the respective grid entry boundaries. The model provides nested grids with entry values at the respective boundaries as calculated from the larger grids. The nested grids can then be set up to provide higher resolution solutions and each grid is therefore accompanied with its own high-resolution bottom grid.

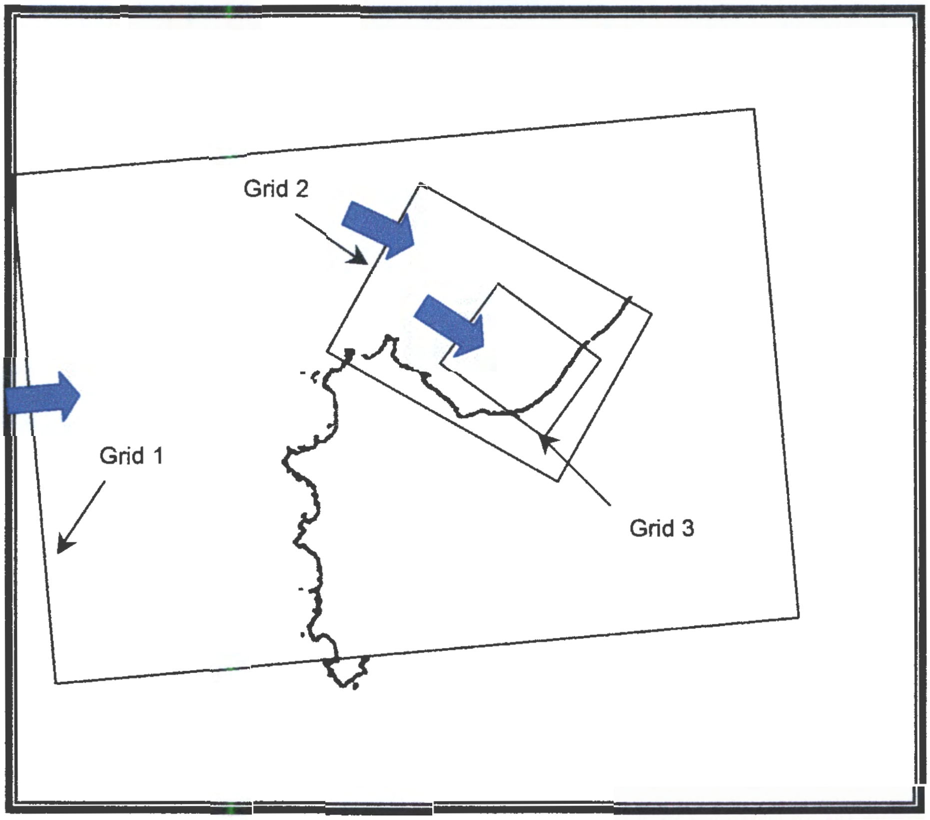

Figure 5.7: Computational grid orientation with wave input boundaries (blue arrows).

Parameter	Grid 1	Grid 2	Grid 3
X - origin	371700	399000	409500
Y - origin	341700	378000	377250
X - length	75000	26000	12250
Y - length	65000	22000	11750
No of x cells	75	52	49
No of y cells	65	44	47
X grid size	1000 (m)	500 (m)	250 (m)
Y grid size	1000 (m)	500 (m)	250 (m)
Angle (CC with east at zero)	5°	330°	324°

Table 5.5: Computational grids orientations.

5.9.4 Spectral Resolution

The directional space for the large grid (grid 1) was set to a sector from –270° to 0°, measured from east. The directional space setting for grids 2 and 3 was circular. The frequency space was kept at the default of 0,05 Hz (lowest frequency), 1 Hz (highest frequency) and the number of frequency bins was 24.

5.9.5 Boundaries

The boundary condition type was kept constant, with the grid boundaries oriented N, W and S for grids 1 to 3 respectively.

5.9.6 Physical Parameters

The following constants were used throughout the model:

Gravity	9.81 m/s^2
North	at 90°
Water Density	1025 kg/m^3
Min Depth	0,05 m
Wind	Constant
Nautical Convention	

The following processes were activated:

Bottom Friction	Jonswap (coeff. = 0,067)
Depth Induced Breaking	B & J model
	Alpha = 1
	Gamma = 0,73
Non-Linear Triad Interactions	LTA
	Alpha = 0,1
	Beta = 2,2

The following various settings were made:

Wind Growth	De-activated
Whitecapping	De-activated
Quadruplets	De-activated
Refraction	Activated
Frequency Shift	Activated

5.9.7 Computational Grid Positioning and Limitations

The Cartesian coordinate system (X',Y') of the bathymetrical area had to be adjusted to accommodate the geographical area ((X,Y) in SA LO 19). The geographical values, which are negative, had to be made positive by adding an arbitrary selected constant to each X and Y value, respectively, as follows:

X' = X + 500 000, and
Y' = Y + 4 000 000

This was applied to all bathymetry and coastline values before entering into the model.

The computational grids are in four dimensions (X, Y, θ, σ) of which the grid in the X-,Y- space must be selected by the user. The up-wave boundary must be selected such that refraction has not influenced the wave field yet. The computational grid must be selected to be larger than the area in concern, as a region exists where the wave field is disturbed by an import of zero energy from the lateral boundaries (Delft3D-Wave User Manual, 2000). This is, however, not the case if the boundary is closed e.g. by land. The angle of the line dividing the disturbed area from the undisturbed area from the up-wave corner points is approximately equal to the half-power width of the directional energy distribution (typically 20° to 40° for waves generated by local wind or 5° to 10° for swell) (Delft3D-Wave User Manual, 2000). This disturbed region in the computational grid is indicated in figure 5.8.

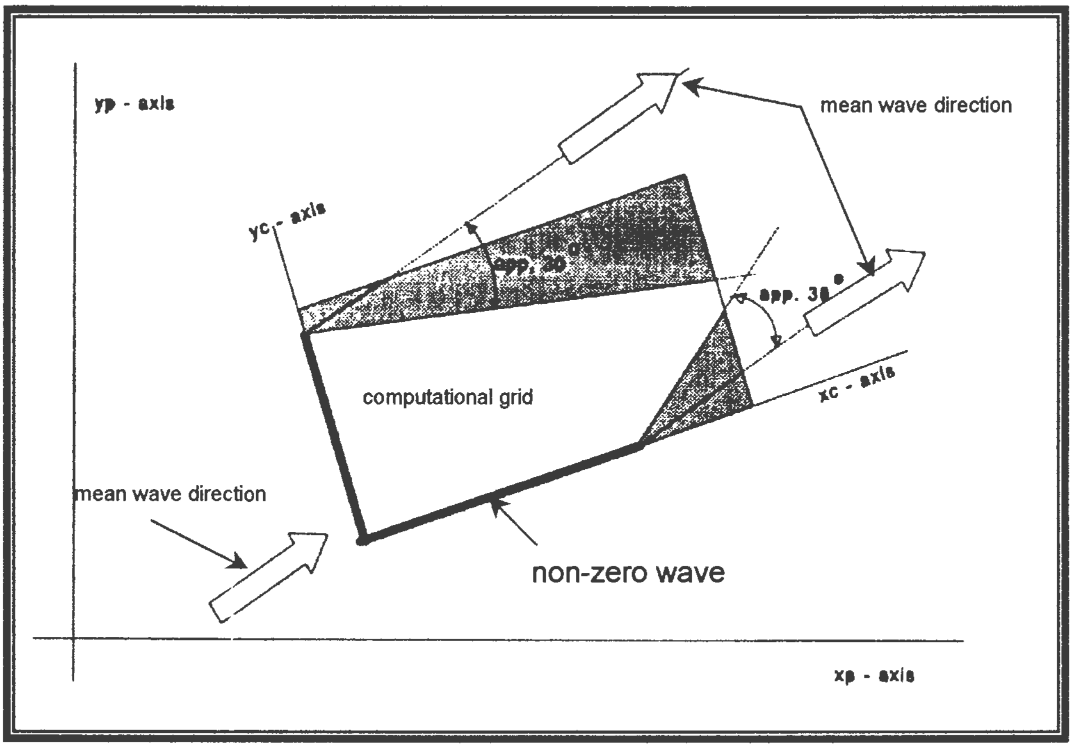

Figure 5.8: Disturbed regions (grey) in computational grid. (Delft3D-Wave User Manual, 2000)

Two main outputs from the modelling are considered in the three case studies: the behaviour of the wave fronts and the maximum energy transfer areas. The next chapter shows the outcomes of the model for the three cases considered.

CHAPTER 6

CASE STUDIES

6.1 Introduction

It must be kept in mind that the data used in the case studies, only refer to the periods indicated in chapter 5, describing the data analysis.

Three case studies were examined for the purpose of the research. These were selected to provide results for wave conditions in the high (extreme), low (known) and intermediate (mode), regions. In the first case the extreme wave recorded by the wave rider buoy was taken, secondly the mode of the significant wave height, directional spreading and period, was taken, and lastly the wave conditions of 18 October 2001 were considered. The reason for the last mentioned case study is that it happened three days prior to Operation Laurel (the closest day to the 21^{st} on which data from the buoy was available).

The following table (table 6.1) indicates the specific data values used as input criteria into the SWAN model, for each case study:

	T	**H**	**Dir (degrees)**	**Time of reading**
Extreme Case	18.1s	9.88m (H_{mo})	262°	1800 (GMT)
Mode	12.5s	2.1m (H_{mo})	223°	-
18 October 2001	7.15s	1.66 (H_{mo})	193°	1200 (GMT)

Table 6.1: Wave data used for specific case studies.

As was discussed in chapter 3, St Helena Bay can be classified as a *relatively protected* to *moderately protected* coastal region. The only real significant feature in the area more or less half way between Laaiplek and Dwarskersbos is an offshore kelp reef and *foul ground* (reef) as indicated by figure 4.2. This reef can be seen in figure 6.1, indicated by the contours in the bay. Figure 6.2 shows the same chart on a slightly smaller scale, indicating bathymetry soundings.

The dots indicating bathymetry are the spot values used in the model as sample points to create the bottom grids and depth files for entry into SWAN. Smoothed out bottom topography is generated by means of triangular interpolation.

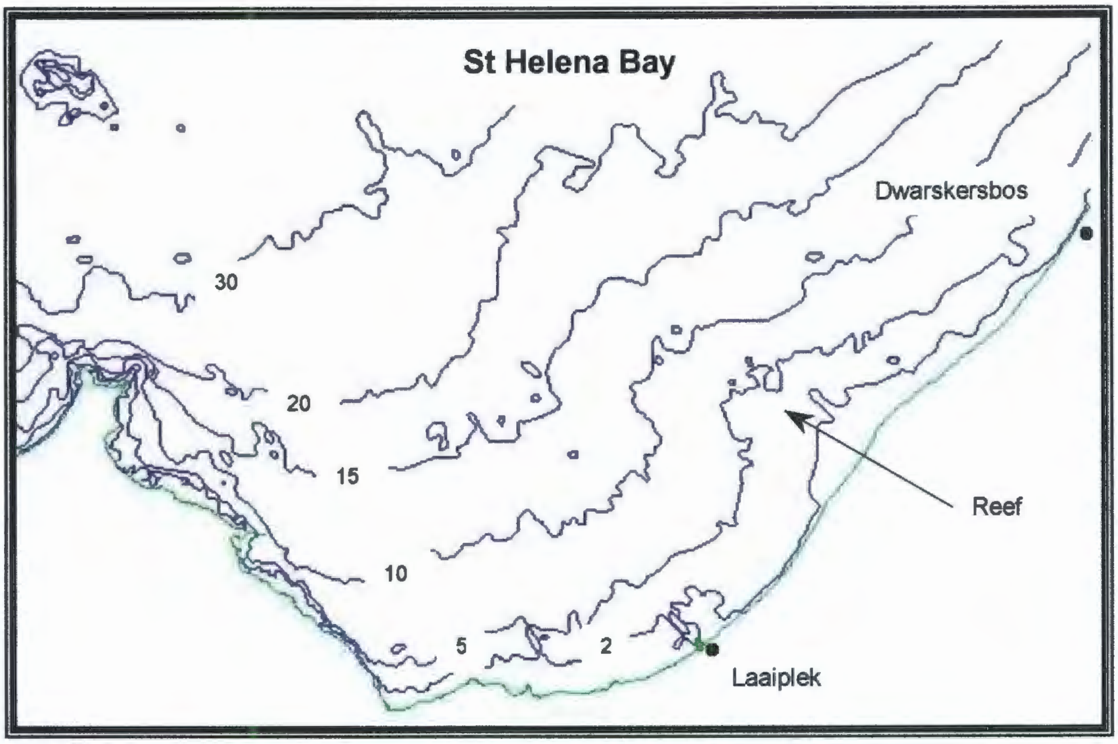

Figure 6.1: Contour map of St Helena Bay (depths in meters below CD).

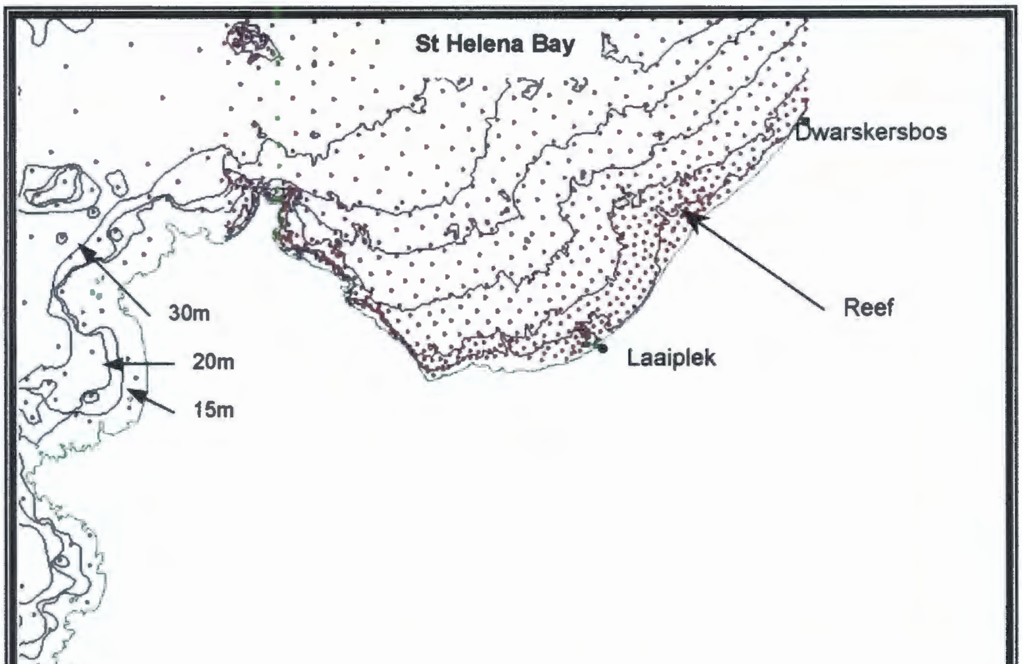

Figure 6.2: Bathymetry map of St Helena Bay (depths in meters below CD).

6.2 Extreme Case Model

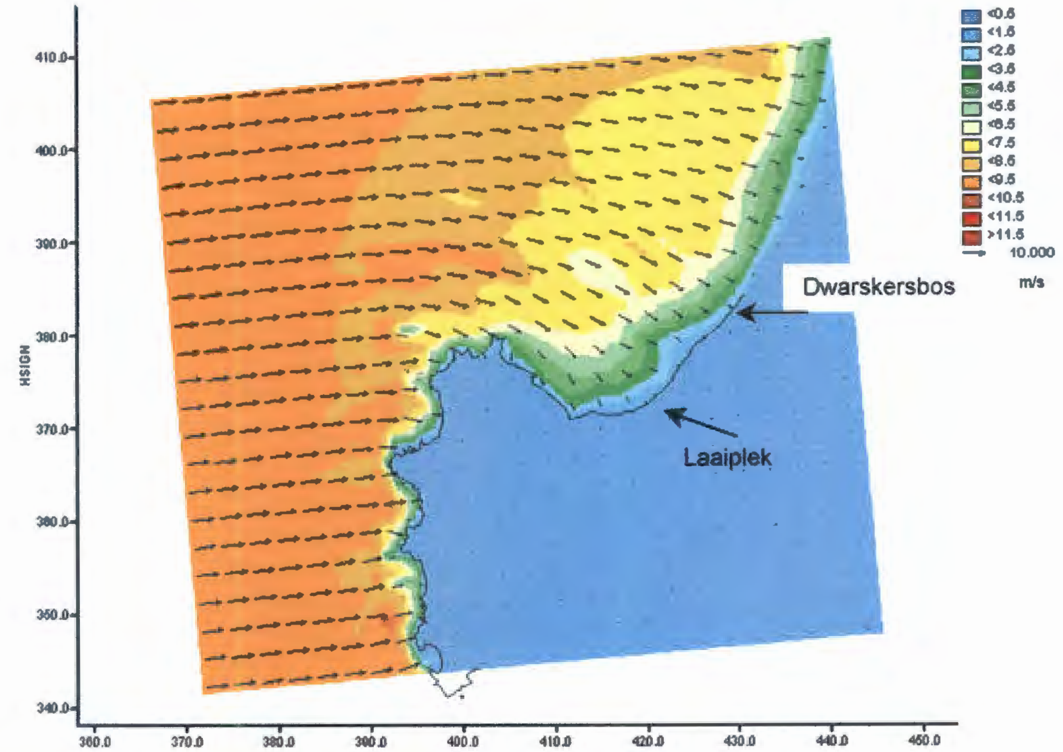

Figure 6.3: St Helena Bay model results of extreme case (small scale).

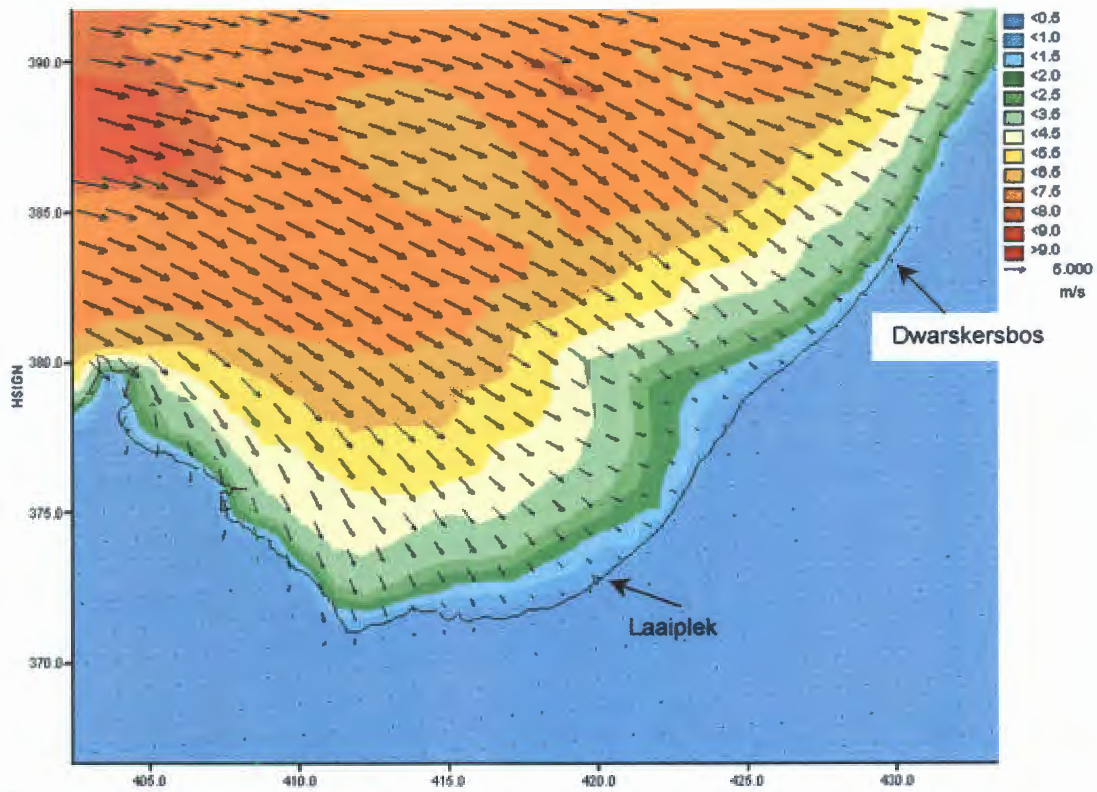

Figure 6.4: St Helena Bay model results of extreme case (large scale).

The extreme case was selected as the highest wave condition recorded by the Slangkop buoy. These values correspond to the storm of 5 September 2001. From the data analysis in chapter 5 and the input directional spreading value, it is clear that in the storm condition the wave fronts approach more from a westerly direction. Due to the waves approaching more into the mouth of the bay, greater effect is observed from the model. Due to the large wave vector values, the vector lengths were adjusted for the visualisation, as indicated in table 6.2.

Wave Vector	**Small Scale**	**Large Scale**
Length of unit vector	0,5 mm	0.9 mm
Distance between vectors	5 mm	6 mm

Table 6.2: Wave vector units used in GPP visualisation.

From figures 6.3 and 6.4 the effect of the reef can clearly be observed. Convergence on the reef can be seen and wave height (H_{mo}) changes are shown. The SWAN model, however, does not use a monochromatic wave, but rather a whole wave spectrum. Thus, it is observed that wave height reduces on the reef rather than to increase due to shallow water. The reason for this phenomenon is the loss of energy to bottom friction and white capping. As $E \propto H^2$, a reduction in wave height is observed. To indicate this energy loss, figure 6.5 shows the energy dissipation in the bay in J/m^2/s. The influence of the reef is clearly visible in figure 6.6. The most energy is converted some distance offshore and the plume of wave height loss in figure 6.4 indicates at what stage the waves start to "feel" the bottom.

These findings from the model are an accurate indication of what can physically be observed, and provides a good wave breaking profile. Further details can be found from the wave spectrum results.

The contrast in energy transfer between the area facing the incoming wave fronts and the effect in the bay is clearly visible. The energy dissipation to the north of Dwarskersbos is ignored, as it is not computed with real bathymetry values.

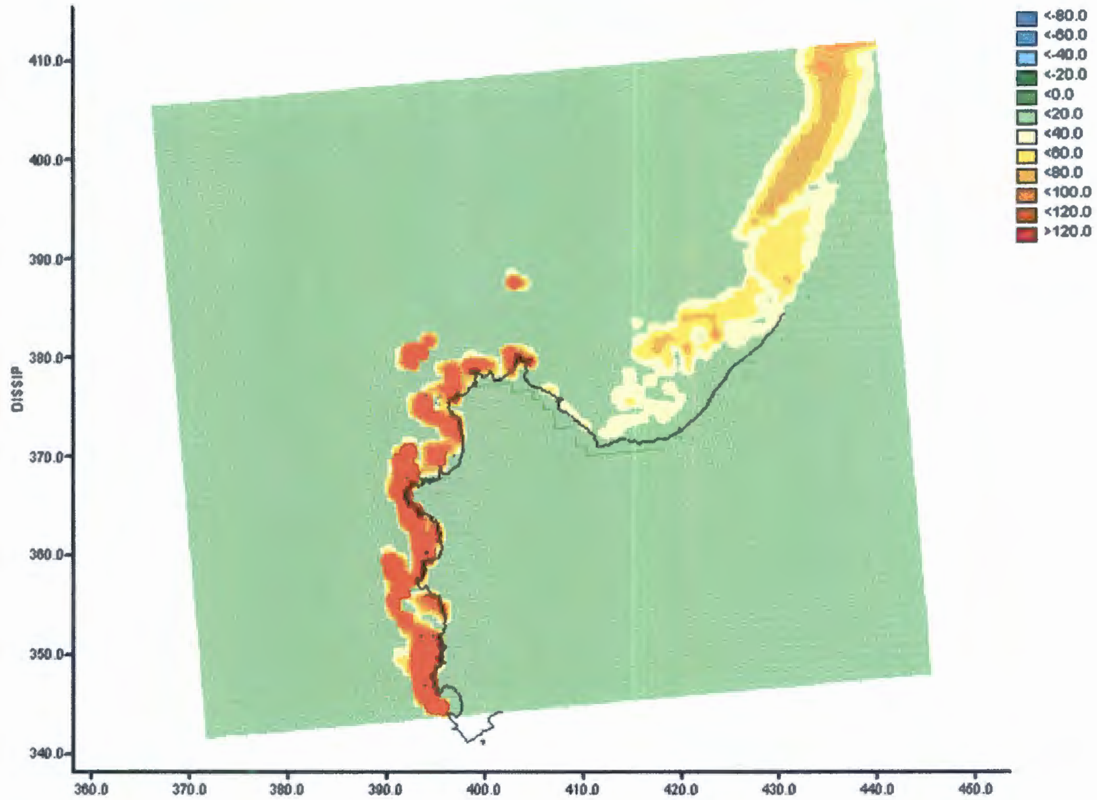

Figure 6.5: Extreme case wave energy dissipation (J/m^2/s)

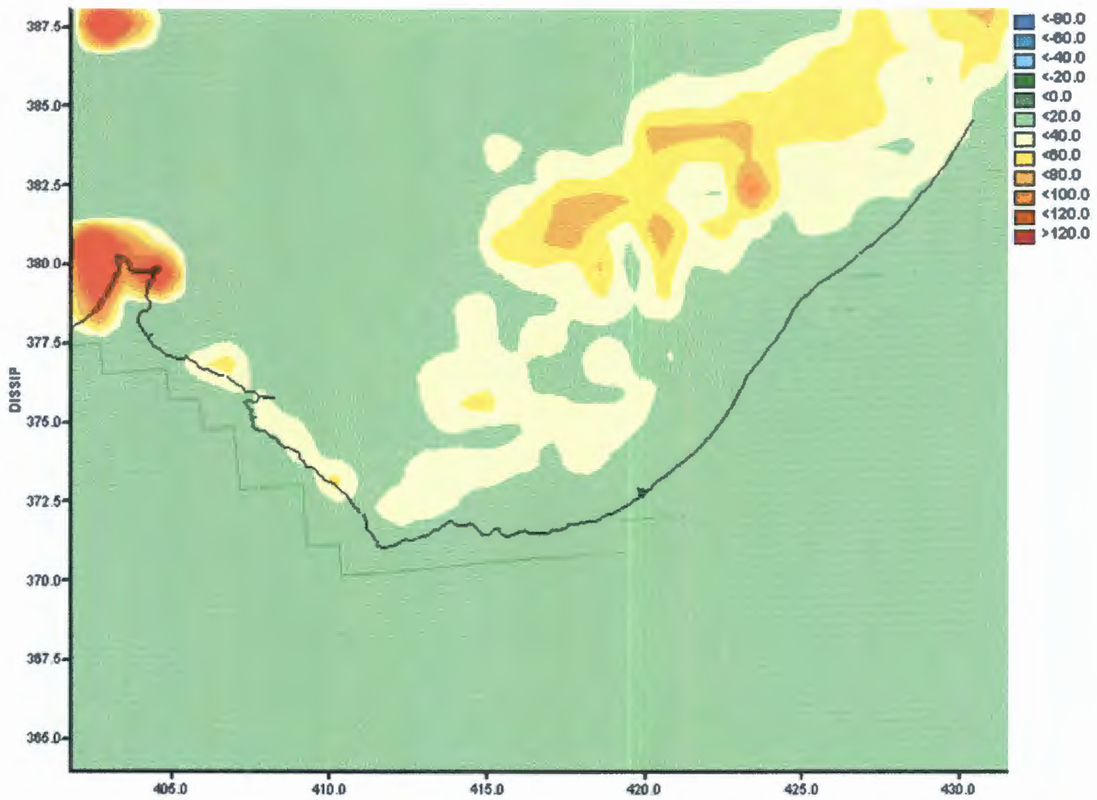

Figure 6.6: Extreme case wave energy dissipation (J/m^2/s).

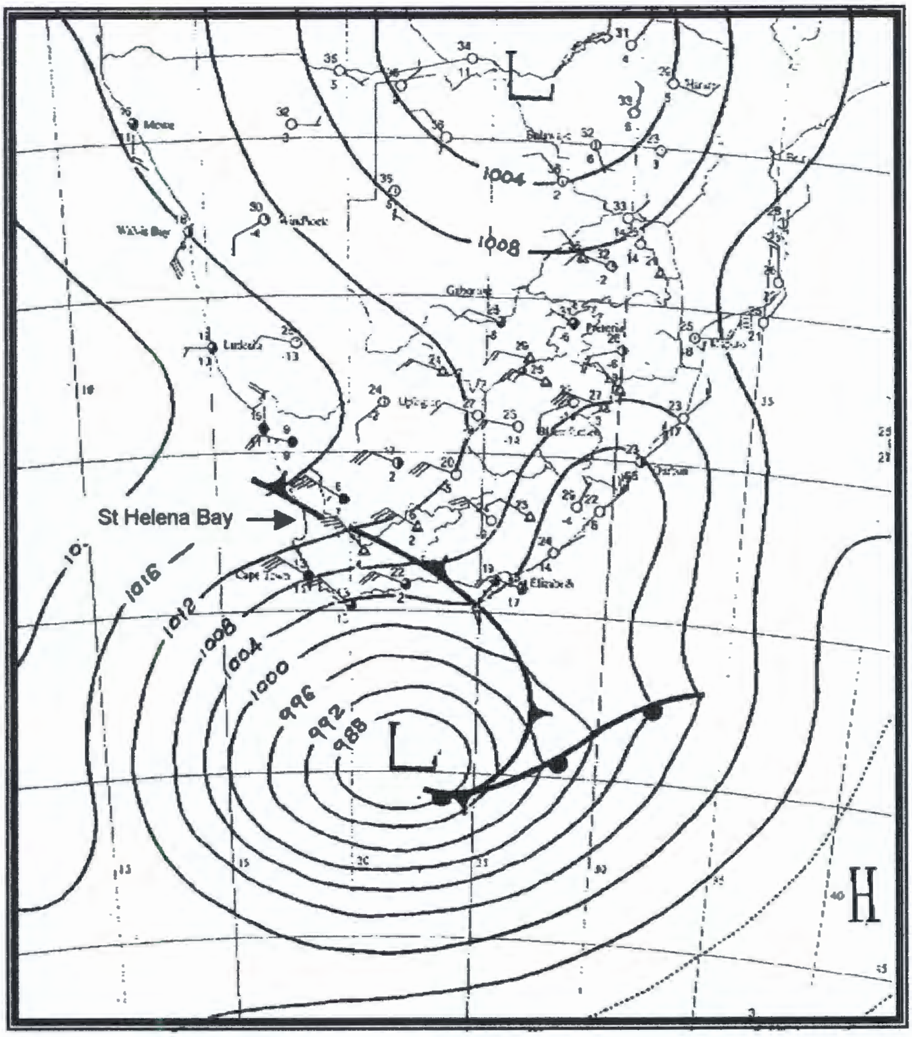

Figure 6.7: Synoptic chart of 5 September 2001. (SAWS, 2001b)

The synoptic chart in figure 6.7 is of 5 September 2001, the day on which the extreme wave condition was recorded. It shows a typical storm condition with a strong northwestern wind, a cold front passing over the country and a deep low-pressure system is visible to the south.

6.3 Mode Case Model

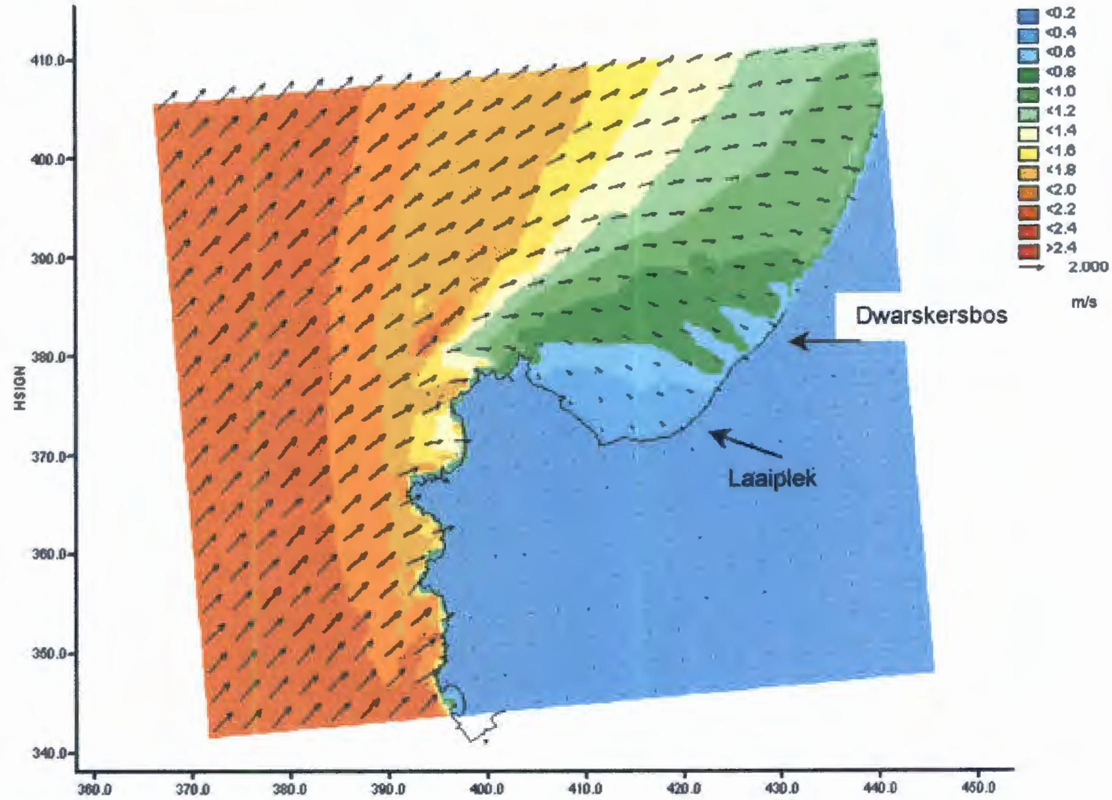

Figure 6.8: St Helena Bay model results of mode case (small scale).

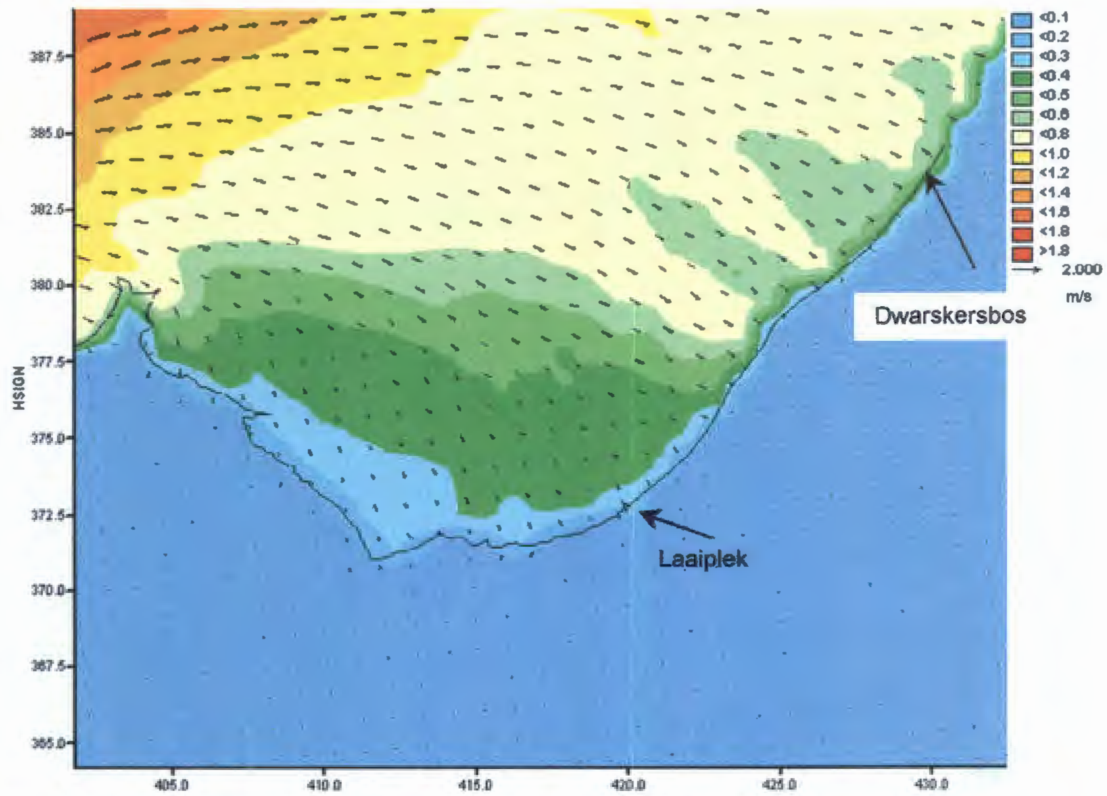

Figure 6.9: St Helena Bay model results of mode case (large scale).

The mode condition is the most frequently occurring score, and in this case, the most frequently occurring values recorded are indicated in figures 5.3 to 5.5 and table 6.1. The mode condition was selected to indicate the general conditions experienced in the bay and how low the most occurring values are.

Due to the input directional change of the wave condition, the mode condition indicates less wave influence in the bay than can be expected in storm conditions. The advancing wave direction is more south of west than in storm conditions, as indicated in the extreme case. Due to the small input values into the model, the vector units in the GPP visualisation, was adjusted according to table 6.3.

Wave Vector	**Small Scale**	**Large Scale**
Length of unit vector	2,5 mm	3 mm
Distance between vectors	6 mm	6 mm

Table 6.3: Wave vector units used in GPP visualisation.

Just south of the reef along the coast, the wave conditions adopt a relative uniform condition, this occurs in the area where the American amphibious landing exercise was conducted.

No wave directional convergence over the reef is visible from the model at this wave height. This indicates that a uniform wave field will approach the shore with only interruptions by offshore rocks at lower tidal conditions. The energy dissipation is indicated in figure 6.10. It shows energy transfer happening at the shoreline and would be in the form of wave breaking. The area where Operation Laurel was conducted would still be clear for amphibian landing exercises, as the energy transfer in this region is negligible.

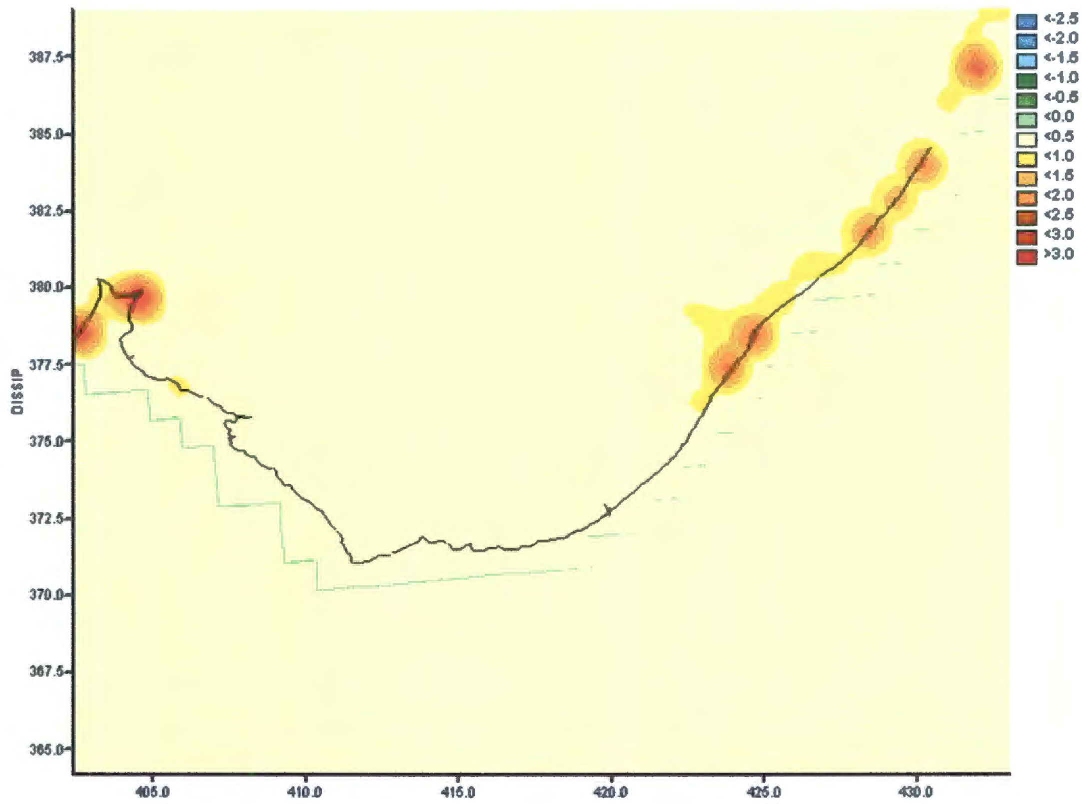

Figure 6.10: Mode case wave energy dissipation (J/m^2/s).

6.4 18 October 2001 Case Model

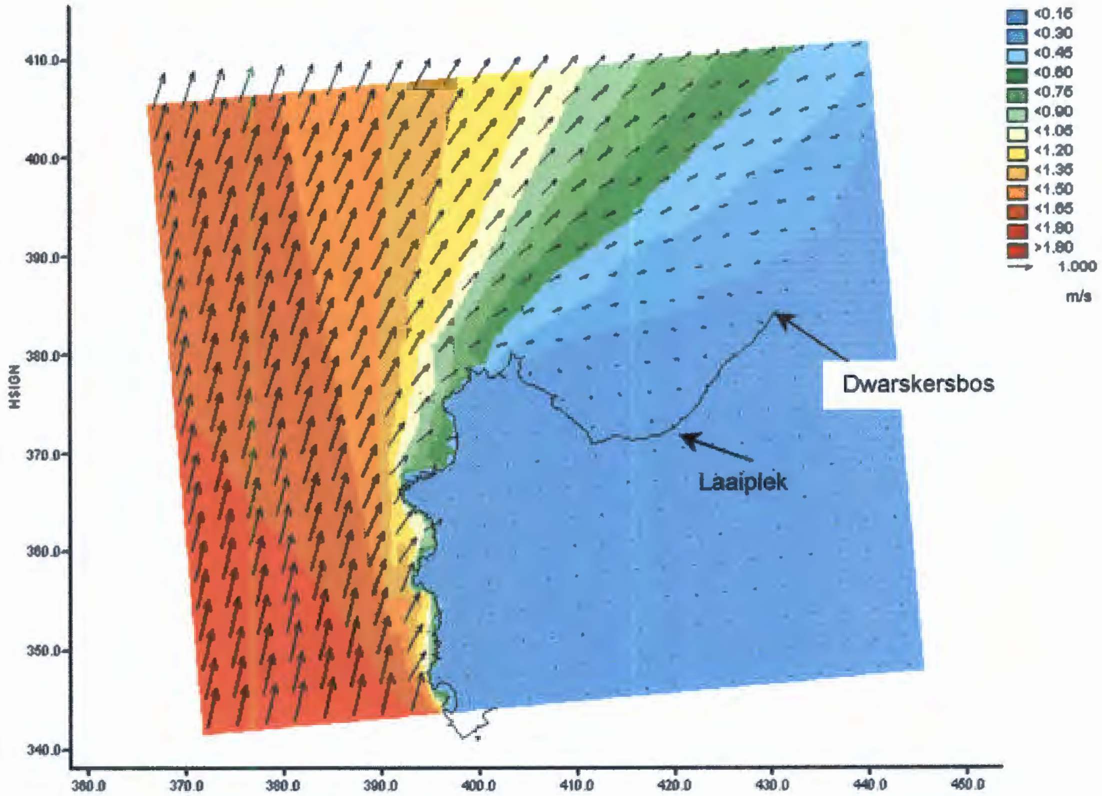

Figure 6.11: St Helena Bay model results of 18 October 2001 (small scale).

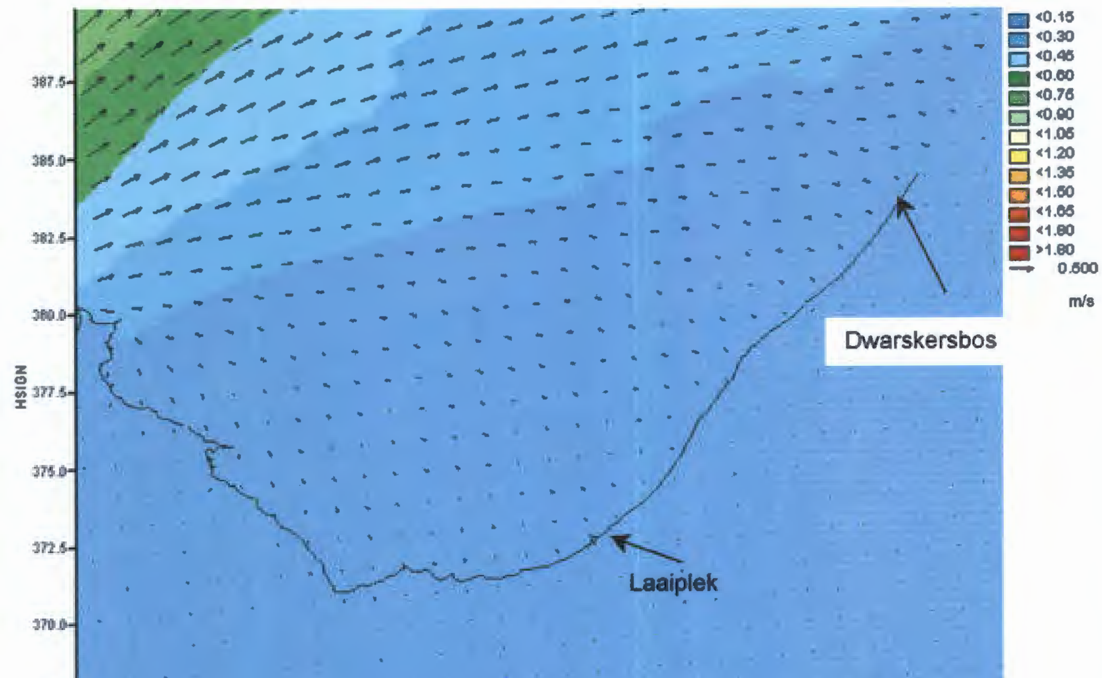

Figure 6.12: St Helena Bay model results of 18 October 2001 (large scale).

The directional spreading of the input wave results in the shielding of the whole of St Helena Bay. In the visualisation program of SWAN (GPP) the settings of the wave vectors had to be increased to be able to appreciate the results. The following table (table 6.4) indicates the values used:

Wave Vector	Small Scale	Large Scale
Length of unit vector	5 mm	5 mm
Distance between vectors	10 mm	5 mm

Table 6.4: Wave vector units used in GPP visualisation.

In figures 6.11 and 6.12 it can be seen that the wave height (H_{mo}) reduces significantly and rapidly to a relative constant height of less than 0,15 m (15 cm) inside the bay. Figure 6.13 indicates the specific synoptic chart for 18 October 2001, three days prior to Operation Laurel. The synoptic chart indicates a typical early summer condition for South Africa with a southeastern wind blowing onshore, a cold front passing far south, with the Atlantic high to the west of the country and a coastal low at the east coast.

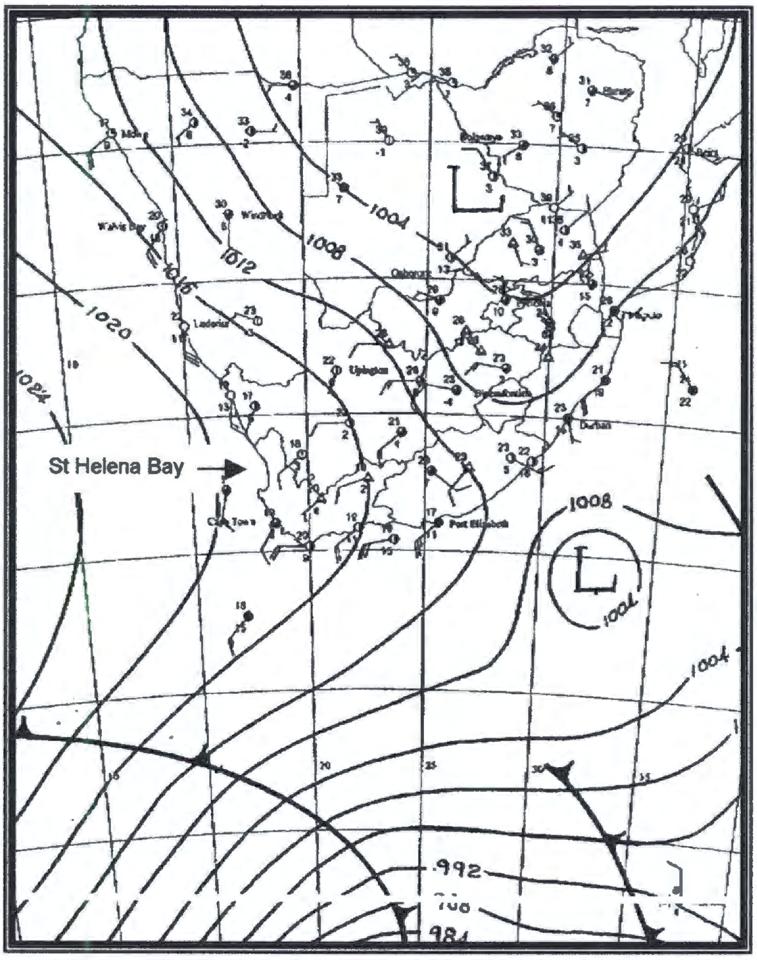

Figure 6.13: Synoptic chart of 18 October 2001. (SAWS, 2001a)

CHAPTER 7

Conclusions

7.1 Operation Laurel

This case study indicates ideal conditions for amphibious landings on the day of concern. From the previous discussion on the mode case, it can be seen that St Helena Bay does not present itself for large wave conditions and is strategically ideal for the type of exercise as was conducted on 21 October 2001.

Wave energy dissipation is negligible in this case study, and no real wave breaking is observed. Calm wave conditions as experienced on 18 October 2001 and from such specific direction, do not indicate the presence of the reef in the bay. Such lack of REA information can be dangerous to an amphibious battle group if no charts are available to indicate such danger. A further unique aspect of St Helena Bay to be considered from a military perspective is the fact that, although it is well protected from the south-western wave onslaught, it is not well protected against the prevailing south-eastern winds in summer (or north western winds in winter). This delta (variable), not indicated by the wave model, must be considered as extremely important for secondary requirements like flying operations. This could also result in the generation of wind-waves in the bay, which could have a lesser influence on amphibious landings, but which will have an effect on the nature of the surf zone.

Considering the river runoff under these conditions, a phenomenon sometimes called "milk water" is possible when the circulation in the bay is reduced. Such unclear water conditions could have a significant effect on sensors in the case of secondary operation requirements. There is, however, still an eddy effect produced in the bay in the form of near surface currents being generated, which will ensure circulation. A return current is generated which follows down south along the coast from north of Lambert's Bay into St Helena Bay at a rate of up to 25 $cm.s^{-1}$ (Boyd et al., in Van der Westhuysen, 2002).

7.2 Mode

The general advancing wave direction is more from the southwest and it has a larger effect on the expected conditions in the bay than was seen in the case of Operation Laurel. The reef's effect is visible from the model in terms of wave height, although it might be difficult to physically observe it during higher tide conditions. It would, however, be sufficient to indicate its presence. The model indicates no significant wave field convergence.

From the large-scale chart (figure 6.9) it can be seen that there are two distinct areas (legs) close to shore where the wave height (H_{mo}) is larger (between 0,6 m and 0,8 m). This effect is directly related to the presence of the kelp reef, as would be expected from the contour chart (figure 6.1). Wave energy dissipation occurs primarily on the shoreline in the form of wave breaking, in line with the reef (figure 6.10). This stands in contrast to both the other case studies and the nature of the surf zone could thus also be expected to be significantly different.

The amphibious landing exercise area, which is to the south of the reef, still experiences uniform wave conditions under these criteria. According to figure 6.10 the energy transfer is almost negligible in this area and hence, making wave conditions mostly fairly predictable it will thus allow for amphibious exercises under these conditions.

The perpendicular wave approach towards the shore (from the model and observed), confirms the formation of cusps. The model also supports the reflective beach type theory. This case study supports the argument that the bay can, in general, be classified as *protected*.

As this case study deals with the wave conditions most often encountered, the classification of St Helena Bay as a protected bay, would be a wise first choice to conduct military operations that could be sensitive to environmental conditions.

7.3 Extreme Case

The wave fronts are seen to enter and uniformly spread inside the bay with no real dead "zones" of sudden lack of wave height. A clear indication of the reef is observed, showing sudden wave height reduction a significant distance offshore. Such energy loss could primarily be attributed to the influences of bottom friction and white capping.

Energy dissipation occurs some distance offshore (figure 6.5) with relatively little breaking happening on the shoreline. This is a distinct difference to the mode case where most energy transfer occurs in the breaker zone. This "wave breaker wall" could still facilitate amphibious landings as the model indicates fewer disturbances in the nature of the surf zone. Crossing of the initial area of energy transfer would be the primary problem to conduct landings. The wave height observed at the surf zone is in the vicinity of 1m. Some operations officers might still regard this as safe for landing, depending on the operational objective.

The apparent total transfer of energy at this offshore region, does, however, indicate a false sense of safety for landing at the area on the reef but landward of the "wave breaker wall". In this case the model cannot be relied on solely for REA, but some additional sources must be consulted. A small channel through the energy transfer region is, however, visible from the model (figure 6.6). This channel, if drawn perpendicular to the coast, coincides with the beach landing area of Operation Laurel. It must be emphasized again that the SA Navy conducted a special survey prior to the operation. Such a source of detailed information would not always be available to make a rapid environmental assessment.

7.4 Conclusion

These three case studies clearly indicate different outcomes for different wave climates. Each case presents itself with its own advantages and disadvantages in terms of going ahead with military operations or not. In all three cases the importance of modelling for littoral operations (amphibious landings) clearly indicates its place in military oceanography.

CHAPTER 8

SUMMARY AND RECOMMENDATIONS

8.1 Introduction

Military oceanography forms an integral part of any navy and the importance thereof for a navy is inversely proportional to its capabilities and size. Knowledge based warfare acts as a force multiplier and is applicable on all terrains of warfare. This concept influences operational efficiency and ocean modelling is an integral part of modern warfare, in the form of "virtual oceanography". In-depth knowledge of the domestic environment assists in making rapid environmental assessments (REA) in foreign environments.

8.2 Summary

The concept of operational efficiency was investigated from a naval perspective. The warfare arena has globally shifted from a blue water concept to a brown water concept after 1991, under the general heading of littoral warfare. Littoral warfare mainly focuses on three principle naval warfare concepts, namely mine warfare, amphibious warfare and special warfare (reconnaissance).

Environmental knowledge, and more specifically oceanographic knowledge, forms a key component of littoral warfare. In this study, one component of oceanographic knowledge was used to indicate its role in operational efficiency. Wave propagation towards the shore has vast effects on all three the above-mentioned littoral naval warfare principles. Ocean modelling as a form of virtual oceanography sets the way for making rapid environmental assessments. The SWAN model was used as a third generation state of the art model, to do wave simulation in St Helena Bay at the South African west coast. Three case studies were considered, viz. the extreme case, Operation Laurel and the mode case (large wave, small wave and *average* wave).

St Helena Bay is well shielded from most wave conditions and qualifies as a moderately protected bay. Although data from a buoy fairly far away was used, applicable results were obtained from the case studies, which were comparable with visual observations For a more realistic result, wave conditions were modelled from the Saldanha Bay mouth to compensate for landmass interference. The different advantages and disadvantages following the outcome of the model for the three case studies, clearly supports decision making in the process of military operational planning.

St Helena Bay is an ideal place to conduct amphibious landings due to its calm and relatively shielded nature. All three case studies indicated an area just north of Laaiplek, to be ideal for an exercise like Operation Laurel. Even in the extreme case operations could be conducted, depending on the operational objective.

8.3 Key Question Revisited

It is now possible to directly answer the question posed at the beginning of this thesis. The modelling of the environment acts as a force multiplier. Pre-engagement strengths and weaknesses are identified in the operational environment (battle space). The model outcome confirms the success of the amphibious landing during Operation Laurel in the research area. The term efficiency indicates the productiveness of the desired effect, especially with minimum waste (Longman Family Dictionary, 1988). The desired effect is to be successful in the military operation. Minimum waste would mean minimum loss of lives and/or equipment. Environmental modelling (pre-knowledge) thus forms an integral part of the operational efficiency of any navy during littoral operations and is integral to the planning of such operation, as was proven by historical events like the Normandy landings.

8.4 Recommendations

The following are recommended:

- An even more realistic picture could be obtained if tidal influences (especially tidal range) were included in the model as well as different wind states. The effect of the Berg River mouth in the bay has not been considered in this study and could have seasonal influences.

- Recent data from a buoy in St Helena Bay itself, could provide an even more realistic output. Such a study could be compared to this thesis model outcomes, which would verify the accuracy of the wave data used from the Slangkop buoy.

- Similar studies should be done for the south and east coast of South Africa, including the possibility of seasonal changes to broaden the SA Navy's knowledge base. This knowledge should then be tested practically to broaden naval capabilities.

- The influence of major (Benguela current) and minor (localised) currents, were omitted. This could have an influence on the bigger picture of amphibious landings. Such currents will also play a role in temperature differences observed, which has various influences on littoral operations.

- The rate of change of wave climate as well as seasonal differences could be determined in future studies. Such environmental studies of ones domestic environment acts as force multiplier during defensive actions.

8.5 Conclusion

The planning of a military operation is always easier than the execution. The man with the rifle in the front line probably does not even know the man in the METOC office. The one has to do what the theorist has concluded. The integration of both skills is what will make the operation a success.

Theory without practice is empty,
Practice without theory is blind!
Unknown

APPENDIX A

Glossary

A

ADCIRC	Advanced Hydrodynamic Circulation Model
ADM	Admiral
AW	Amphibious Warfare
AWK	Afdeling Waterwegen Kust (Belgium)

B

BMO	(British model)

C

C4ISR	Command, Control, Communications, Computers & Intelligence, Surveillance and Reconnaissance
CAPT	Captain
CD	Chart Datum
CDR	Commander
CDRE	Commodore
CIGCES	Centre for Interactive Graphical Computing of Earth Systems
cm	centimetre
COAMPS	(High Resolution Atmospheric Prediction system)
CSIR	Council for Scientific and Industrial Research

D

3D	3-Dimentional
DMI	Danish Meteorological Institute
DNMI	Norwegian Meteorological Institute
Dr	Doctor
DWD	Deutscher Wetterdienst

E

E	East
E	Energy (wave)
EOD	Explosive Ordinance Disposal
EuroGOOS	European Global Ocean Observing System

F

FNMOC	Fleet Numerical Meteorology and Oceanography Center
FNOC	Fleet Numerical Oceanography Center
ft	feet (length)

G

GFDN	(Tropical Cyclone Model)
GKSS	(German National Research Facility)
GONO	(Dutch model)
GPP	General Post-processing Program
GUI	Graphical User Interface

H

H	Height (wave)
H_{mo}	Significant Wave Height
HISWA	(Model by Delft University of Technology)
HRAY	Hugo Biermann Ray Trace Model
HYPA	Hybrid-parametric spectral wave model for shallow waters
HYPAS	(see HYPA) sea level can change

I

ICAO	International Civil Aviation Organisation
IMO	International Maritime Organisation
IMT	Institute for Maritime Technology
IOPS	Integrated Ocean Prediction System
IST	Instituto Superior Técnico (Portugal)
ITCZ	Inter Tropical Convergence Zone

J

J	Joule
JONSWAP	Joint North Sea Wave Project

K

KBW	Knowledge Based Warfare
Km	kilometre
KNMI	Koninklijk Nederlands Meteorologisch Instituut

L

LO	Local Ordinate (system)

M

m	metre
mm	millimetre
MCM	Mine Counter Measures
MDD	Maritime Data Display
METOC	Meteorology and Oceanography
MOE	Measure of Effectiveness
MODAS	Modular 3-Dimentional Ocean Data Assimilation System
MRI	(Japanese model)

MUMM	Management Unit of the North Sea Mathematical Model
MW	Mine Warfare

N

N	North
NASA	National Aeronautical & Space Administration
NATO	North Atlantic Treaty Organization
NAVOCEANO	Navy Oceanographic Office
NCEP	National Centres for Environmental Prediction
NCOM	Upper Ocean and Coastal Ocean Prediction (model)
NEDWAM	Netherlands Wave Model
NGLI	Northern Gulf (Of Mexico) Littoral Initiative
NLOM	Deep Ocean Mesoscale Prediction (model)
NM	Nautical Mile
NOAA	National Oceanic & Atmospheric Administration
NOGAPS	(Atmospheric Prediction System)
NOWAMO	(Norwegian wave model)
NPA	National Ports Authority (South Africa)
NRL	Naval Research Laboratory
NSSM	Navy Standard Surf Model
NW	Northwest

O

OCEAN MVOI	3_Dimentional Ocean Multi-Variate Optimal Interpolation System
OIS	Ocean Information Systems
ONR	Office of Naval Research

P

PC	Personal Computer
PIPS	Polar Ice Prediction System
Prof	Professor
PROPS	Propagation Model (Spain)

Q

R

REA	Rapid Environment Assessment
REF/DIF	Refraction/Diffraction model
REFDIF	Refraction/Diffraction model
REFRAC	Refraction model (Germany)
ReloPOM	Rapidly Relocateable Ocean Prediction
ROAMER	Rapid Ocean Analysis Modelling Evaluation Relocatable (system)
RSA	Republic of South Africa

S

s	seconds
S	South
SA	South Africa
SACLANT	Supreme Allied Commander Atlantic
SADCO	South African Data Centre for Oceanography
SAN	South African Navy
SANDF	South African National Defence Force
SAS	South African Ship
SAST	South African Standard Time
SAWS	South African Weather Services
SE	Southeast

SM	Southern Cross Medal
SMB	Sverdrup, Munk and Bretschneider
SMOD	Sonar Model
STWAVE	Nearshore Spectral Wave Model
SW	Southwest
SWAMP	(International wave model testing and intercomparison program)
SWAN	Simulating WAves Nearshore
SWAFS	Coastal Ocean Prediction model (various fixed regions)

T

T	Period (wave)
TEDS	Tactical Environmental Data Server (USN)
TOPS	(Upper ocean mixed layer forecast model)
TRAY	Tactical Ray Trace Model

U

UCT	University of Cape Town
UK	United Kingdom
US	United States (of America)
USS	United States Ship
USN	US Navy

V

VAG	Vague (French for "wave" pronounced "vag")
VAGATLA	VAG model for Atlantic
VAGMED	VAG model for Mediterranean
VOS	Voluntary Observation Ship

W

W	West
WAM	Wave Model
WINCH	(Norwegian regional wave model)
WWII	World War II
WW3	Wave Watch III

X, Y, Z

APPENDIX B

References

1. Allard, R. A., Kaihatu, J., Hsu, Y. L. & Dykes, J. D., 2002. **The Integrated Ocean Prediction System (IOPS)**. Oceanography Vol. 15 No.1/2002: 67 – 76.

2. Brackenbury, L. Lieutenant USN. **Det brings "highly specialized" mission to ARG**. US Navy [online]. http://www.c7f.navy.mil/news3/7frel748.html [2003]

3. Brown, A. C. & McLachlan, A., 1990. **Ecology of Sandy Shores**. Elsevier Science, New York.

4. Brown, E., Colling, A., Park, D., Phillips, J., Rothery, D. & Wright, J., 1999. **Waves, Tides and Shallow-Water Processes.** (2nd Ed). The Open University. Butterworth-Heinemann, England.

5. Burnett, W., Harding, J, Heburn, G., 2002. **Overview of Operational Ocean Forecasting in the US Navy: Past, Present & Future**. Oceanography Vol. 15 No.1/2002: 4 – 12.

6. Calhoun, C. R. 1981. **TYPHOON: The Other Enemy**. Annapolis, Maryland: NAVAL INSTITUTE PRESS.

7. Chu, P. 1999. **Thesis Topics**. Naval Postgraduate School, Monterey [online]. http://www.oc.nps.navy.mil/~chu/thesis.html [11/10/2001]

8. Chu, P. & Haeger, S. D. **NAVOCEANO-NPS Thesis Program on Littoral Warfare Oceanography**. Naval Postgraduate School, Monterey US [online]. http://www.oc.nps.navy.mil/~chu/ [28/08/2003]

9. Collins, J. M., 1998. **Military Geography for Professionals and the Public.** Washington DC. National Defence University Press.

10. Cox, A. T. & Cardone, V. C. **20 Years of operational forecasting at oceanweather** [online]. Oceanweather Inc. http://www.oceanweather.com/about/papers/20%20Years%20of%20Operational%20Forecasting%20at%20Oceanweather.pdf [22/09/2003]

11. Davis VI, G. W. 1995. **Naval Oceanography For the Future**. Sea Technology, 36: 13 – 17.

12. Delft3D-Wave User Manual, 2000. **Introduction to Delft3D-Wave: SWAN**. August 2000 version 2: 2-1 to 2-3.

13. Flather, R. A., 2000. **Existing Operational Oceanography**. Coastal Engineering 41: 13 – 40. Elsevier.

14. Garrison, T, 2002. **Oceanography: An Invitation to Marine Science**. Pacific Grove, CA. United States of America. Brooks/Cole Thomson Learning.

15. GKSS Institute for Coastal Research. System Analysis and Modelling [online]. http://dvsun3.gkss.de/pages.php?page=k_m_models.html&language=e&version=g [22/09/2003]

16. Goosen, J. C., 1973. **South Africa's Navy – The First Fifty Years**. W. J. Flesch and Partners, Johannesburg.

17. Hicky, C. D. D., 1998. **Checkmate – Self-Burying Mine**. Sea Technology, Vol. 39 (4): 37 – 42.

18. Hughes Jr, W. P. Captain USN (ret), 2000. **Fleet Tactics and Coastal Combat.** (2nd Ed). Annapolis, Maryland. Naval Institute Press.

19. Kamfer, A. CAPT(SAN), 2001. **Report of Survey: Survey Order 2/01: Laaiplek Beach Survey**. Hydrographer of the South African Navy (SAS PROTEA). 2001. (with special permission).

20. Lefèvre, J-M, 2003. Correspondence by e-mail re VAG.

21. Longman Family Dictionary, 1988. Chancellor Press, London.

22. Lutjeharms, J. R. E., Wainman, C. K., Gildenhuys, S., 1998. **Environmental Textbook SAN**. Report prepared for IMT [RESTRICTED]. Institute for Maritime Technology.

23. Mitsuyasu, H., 2002. **A Historical Note on the Study of Ocean Surface Waves**. Journal of Oceanography, Vol. 58: 109 - 120.

24. NGLI. **Northern Gulf of Mexico Littoral Initiative**. [online]. http://128.160.23.41/Products/modeling/swan [21/08/2003]

25. Ocean Studies Board, Commission on Geosciences, Environment, and Resources, National Research Council. **Oceanography and Mine Warfare**. Washington DC. National Academy Press, 2000.

26. Padilla-Hernández, R. & Monbaliu, J., 2001. **Energy balance of wind waves as a function of the bottom friction formulation**. Coastal Engineering 43: 131 – 148. Elsevier.

27. Patch, J., 2003. **Don't Ignore Sea Control**. Proceedings, October: 40 - 42.

28. Prandle, D., 2000. **Operational Oceanography - A View Ahead**. Coastal Engineering 41: 353 – 359. Elsevier.

29. Ris, R. C., Holthuijsen, L. H. & Booij, N., 1999. **A Third Generation Wave Model for Coastal Regions**. Journal of Geophysical Research, Vol.104 No. C4 April 15, 1999: 7667 – 7681.

30. Robinson, A. R. & Sellschopp, J., 1999. **Predictive Skill Experiments for Coastal Seas REA** (a working paper) [online]. http://people.deas.harvard.edu/~robinson/PAPERS/Pred_Skill.html [26/08/2003]

31. Rosenberg, L. H. & Anderson, R. T. 2001. **Stopped Short by Mines**. Proceedings, January 2001: 66 – 68.

32. Rossouw, J., 1989. **Design Waves for the South African Coastline**. Doctoral thesis. University of Stellenbosch.

33. SA Navy Review, 2001. **South African Navy Review 2001**. On file [RESTRICTED].

34. SANDF Intranet, 2003. **Role of the SA Navy**. SANDF Intranet online (Restricted).

35. SAWS, 2001a. **Daily Weather Bulletin – 18 October 2001.** South African Weather Services.

36. SAWS, 2001b. **Daily Weather Bulletin – 5 September 2001.** South African Weather Services.

37. Sellschopp, J., 1999. **Rapid Environmental Assessment**. Naval Forces 3/99, 1999: 110 – 115.

38. Sverdloff, J. CPO, 2001. **Combined Forces, Humanitarian Relief Training Exercise.** Navy News 20 No. 6, 2001: 20 – 23.

39. Tolman, H. L. **WAVEWATCH III Model description** [online]. http://polar.wwb.noaa.gov/waves/wavewatch/wavewatch.html [22/09/03]

40. Uys, A. J. K. CDR, 2003. Officer commanding SAS GELESHEWE. Personal and telephonic interviews (Restricted).

41. Van der Wal, D. & Pye, K. 2003. **The use of historical bathymetric charts in GIS to assess morphological change in estuaries**. The Geographical Journal, Vol 169, No 1, March 2003: 21 – 31.

42. Van der Westhuysen, A. J., 2002. **The Application of the Numerical Wind-Wave Model SWAN to a selected Field Case on the South African Coast**. Master's thesis in Civil Engineering, Stellenbosch.

43. Van Heerden, J. & Hurry, L., 1987. **South Africa's Weather Patterns: An Introductory Guide**. Acacia Books, Pretoria.

44. Wainman, C. K., 2003. **Military Oceanographic Requirements of the SAN: Proposed IMT Tasks for 04/05**. Memo to Combat Development Team, 2003. [with permission].

45. Yunker, C. Major, 2001. **MCM Upgrades Help Solve Riddle of Access Denial**. Proceedings, September: 68 - 70.